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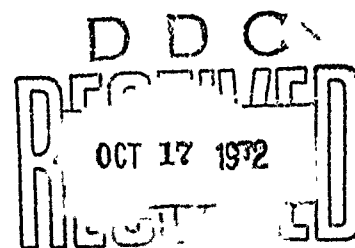
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INSTALLATION OF A SELF-SEALING MATERIALS
SYSTEM IN A C-130 INTEGRAL FUEL TANK WING

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Northrop Corporation
Aircraft Division



TECHNICAL REPORT AFML-TR-72-30

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FOREWORD

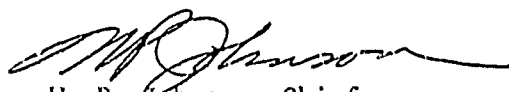
This report was prepared by the Northrop Corporation Aircraft Division, Hawthorne, California, under USAF Contract No. F33615-71-C-1675. The contract work was performed under Project No. 1559, "Operational Support Equipment Test and Evaluation", Task No. 313, "Self-Sealing Integral Fuel Tanks", and was administered under the direction of the Air Force Materials Laboratory. The program monitor was Mr. T. L. Graham, LNE, of the Elastomers and Coatings Branch of the Nonmetallic Materials Division, AFML.

Dr. R. M. Heitz served as the principal investigator in this program. Other Northrop personnel who made major contributions in this research program were: Dr. G. H. Bischoff and Messrs. F. Hill, R. McGaffin, J. Superata, J. H. Rudy, and D. A. Karlson.

The contractor's report number is NOR 72-6. This report covers work from 15 June 1971 to 15 January 1972.

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This technical report has been reviewed and is approved.



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ABSTRACT

The objective of this program was to adapt a newly developed self-sealing integral fuel tank materials system to a C-130 integral wing tank and evaluate its resistance to slosh and vibration damage as well as its protective capabilities against small arms ground gunfire. The selected system consists of a combination of flexible ballistic nylon laminates (corrugated and flat) and precompressed Buna-N closed-cell foam.

This system, when installed in a C-130 wing integral fuel tank section, was found to withstand slosh and vibration tests.

In firing tests of this system installed in a C-130 wing integral fuel tank section, promising results were obtained. The damage control system proved successful in limiting the damage to the C-130 skin structure. The self-sealing system was successful for many .50 caliber AP and API impacts. When the projectiles hit a rib longitudinally and tumbled immediately behind the tank entry skin structure, large areas of the tank were damaged and sealing was only partially effective.

When installed in the slosh and vibration tests tank, the weight of the system was 1.70 pounds/foot² and its thickness exceeded the height of the structural ribs (5/8-inch) by 3/16 of an inch. By comparison when installed in the firing tests tank, the weight of the system was 1.85 pounds/foot² and its thickness exceeded the height of the structural ribs (7/8-inch) by 3/16 of an inch.

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SECTION I

INTRODUCTION

Small-arms ground fire is still a hazard to aircraft fuel systems. A 20mm or smaller size projectile puncturing an aircraft fuel tank may produce leaks causing loss of fuel, fires, explosions, and possibly destruction of the aircraft. In view of these hazards and their implications on aircraft safety, development of new and improved passive defense techniques are required.

The objective of this investigation is to adapt a damage control and self-sealing integral fuel tank materials system, developed under a related Air Force Contract, F33615-70-C-1426, to a C-130 wing integral fuel tank and conduct evaluations for resistance to slosh and vibration, and resistance to damage by .50 caliber AP and API and 20mm AP projectile impacts.

The work activities on this contract are divided into five areas, and the accomplishments of each are reviewed in Section II of this report.

SECTION II

TECHNICAL DISCUSSION

A. SIMULATED VERTICAL SHOTS IN C-130 SKIN STRUCTURE SECTIONS

In preparation for the final selection of the damage control and self-sealing systems to be installed in the C-130 slosh and vibration test tank and firing test tank, simulated impact tests in C-130 skin structure sections were performed. In these tests the damage control and the self-sealing systems used for protecting the C-130 wing tank skin structure against small-arms ground fire (.50 caliber AP and API and 20 mm. AP) are shown in Figure 1. They are a combination of flexible ballistic nylon laminates (corrugated and plain) and precompressed Buna-N closed-cell foam. A method for fabricating these laminates was developed and will be described below in Section C.

Using this method, corrugated and plain laminates were fabricated from which several C-130 test panels were fabricated, using C-130 skin structure sections taken from wing station OWS 421 to OWS 456 (Figure 2). The skin thickness of the section was .050-inch and the rib height was 5/8-inch. The panels were fabricated so that they could be mounted to a two-foot-cube tank for the firing tests. Each panel was mounted to the test setup as shown in Figure 3. This setup was used to simulate vertical shots. The PVC plastic film simulated the liquid level inside the tank. In each test, a high-speed motion picture was taken to observe (a) the impact at the entry and the exit tank sides, and (b) to observe the phenomena taking place inside the tank. The panel configurations tested are shown in Figure 4.

1. C-130 Skin Structure Section without Any Protection

In this series of tests, panels having a configuration of Structure A (Figure 4) were mounted at the entry and exit side of the tank setup. In test, when the .50 caliber AP projectile impacted between two ribs at the tank entry side, a clean hole with no rupturing was obtained in the entry panel skin. At the tank exit side, the projectile penetrated the panel in a tumbled condition hitting a rib and rupturing the exit C-130 panel heavily. However, when the projectile hit a rib of the panel at the tank entry side, the entry panel skin structure ruptured heavily as shown in Figure 5. The panel at the tank exit side was hit by the tumbled projectile. Rupture was minor, as is shown in Figure 5.

2. C-130 Skin Structure Section Protected with the Damage Control System Only

Panels having the configuration of Structure B (Figure 4) were mounted at the entry and exit side of the tank setup. The same impact conditions as for Structure A configuration were used; that is, a penetration between two ribs and a hit of a rib. When the projectile (.50 caliber AP) penetrated between two ribs at a 90-degree angle of incidence, the entry panel skin showed only a small hole. This was almost sealed by the corrugated laminate as shown in

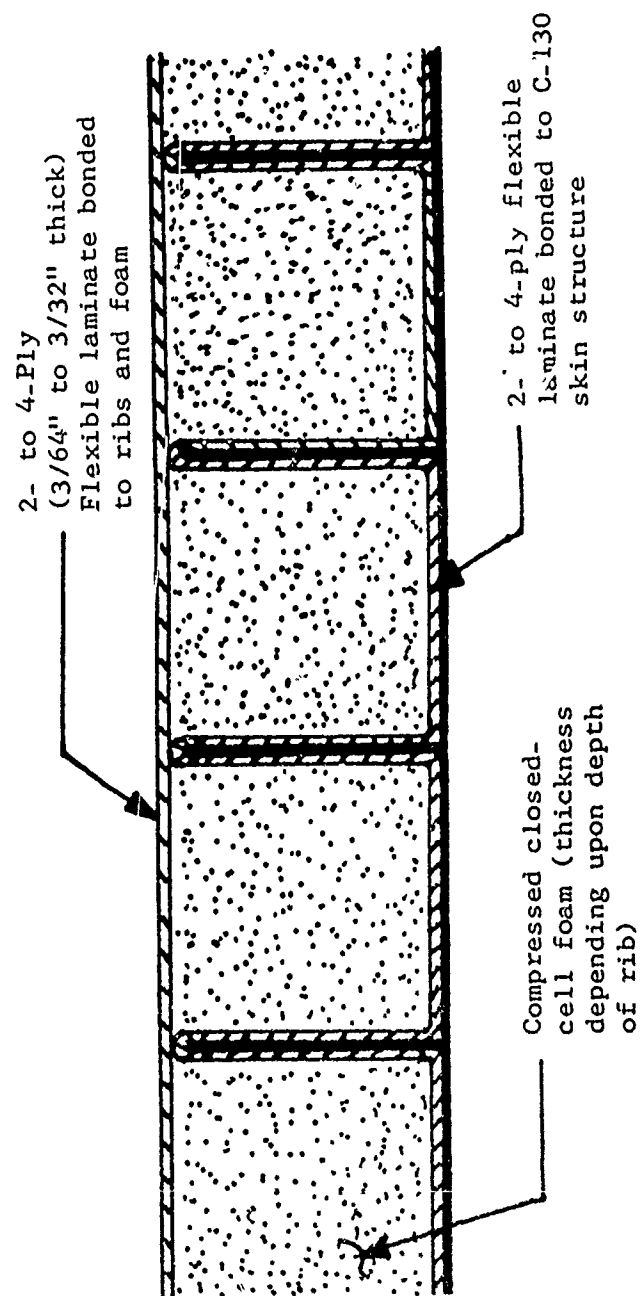


FIGURE 1. C-130 SELF-SEALING PANEL CONFIGURATION

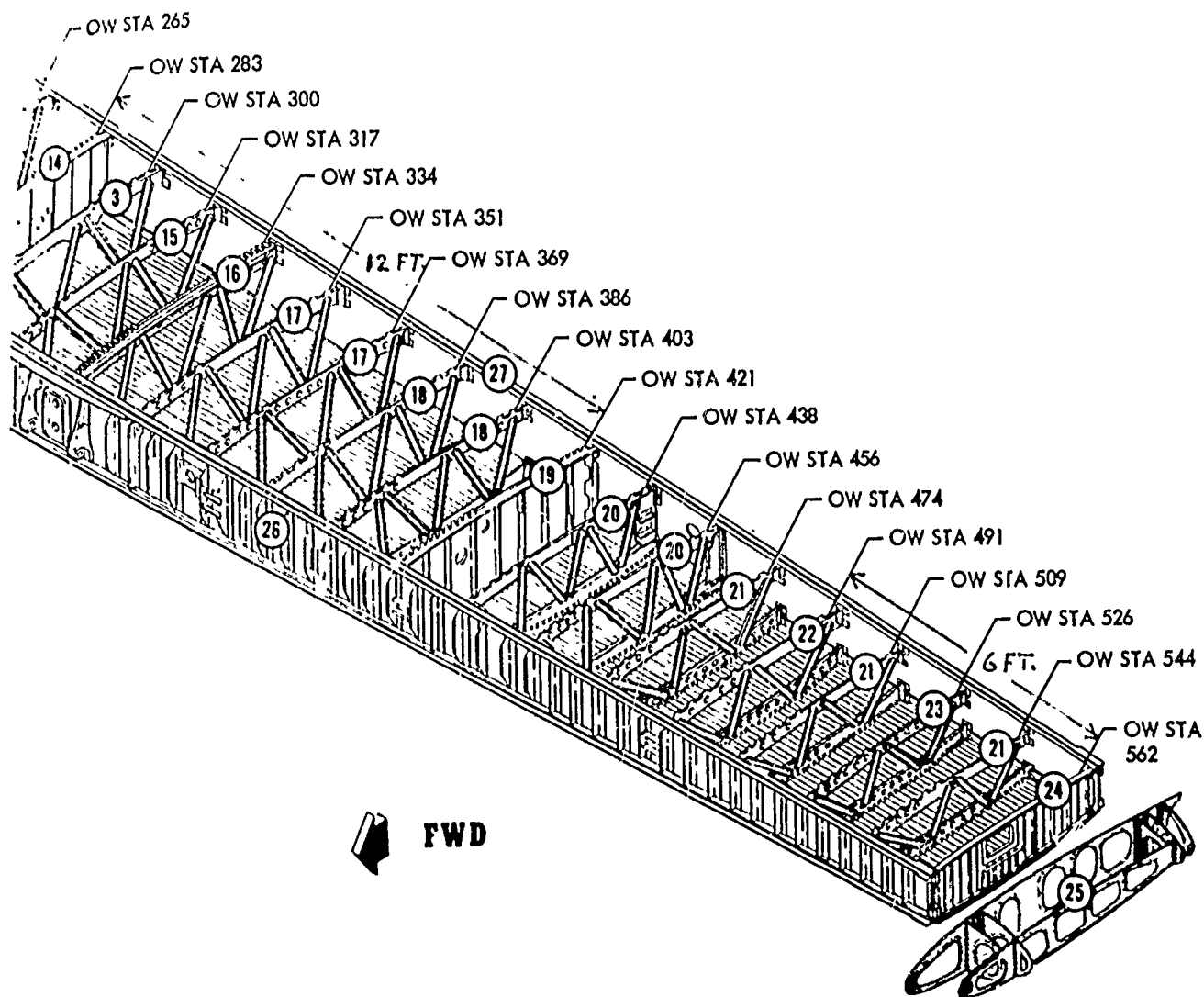


FIGURE 2. OUTER WING BOX BEAM STRUCTURE

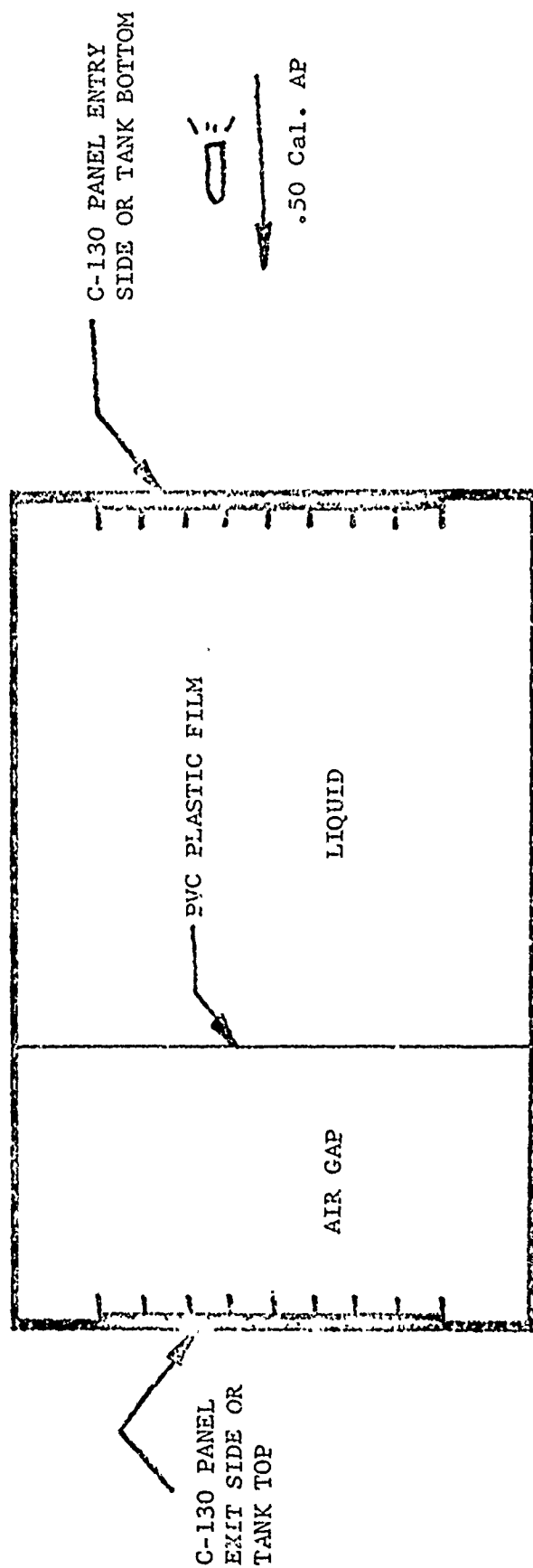
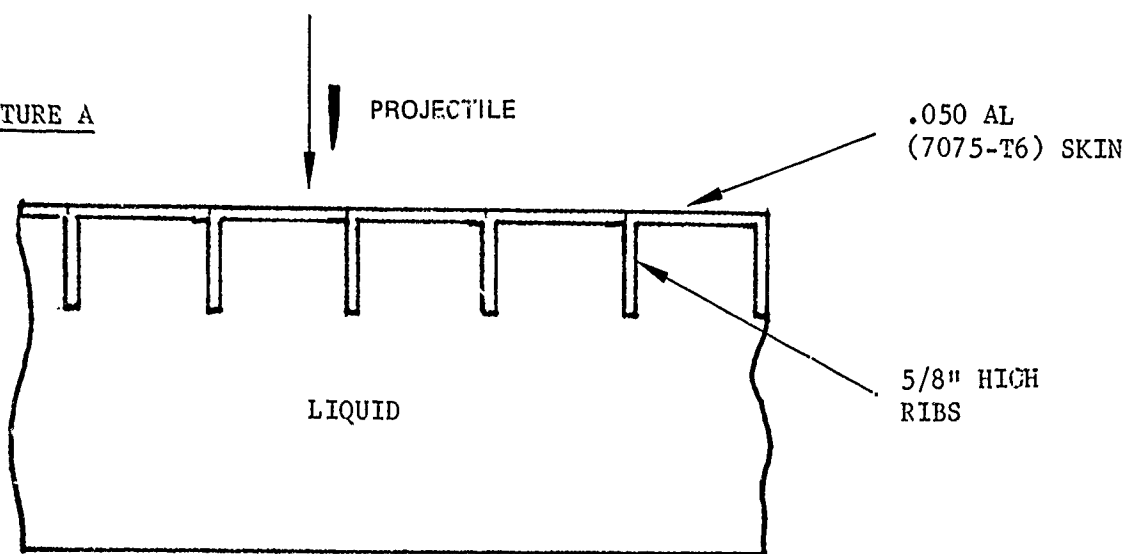
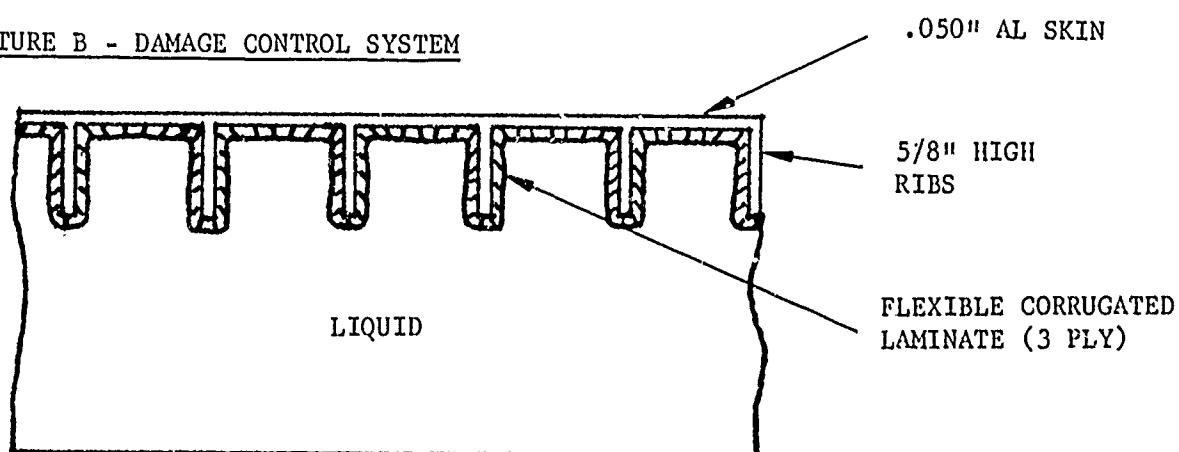


FIGURE 3. TEST SETUP SIMULATING VERTICAL SHOTS

STRUCTURE A



STRUCTURE B - DAMAGE CONTROL SYSTEM



STRUCTURE C - SELF-SEALING SYSTEM

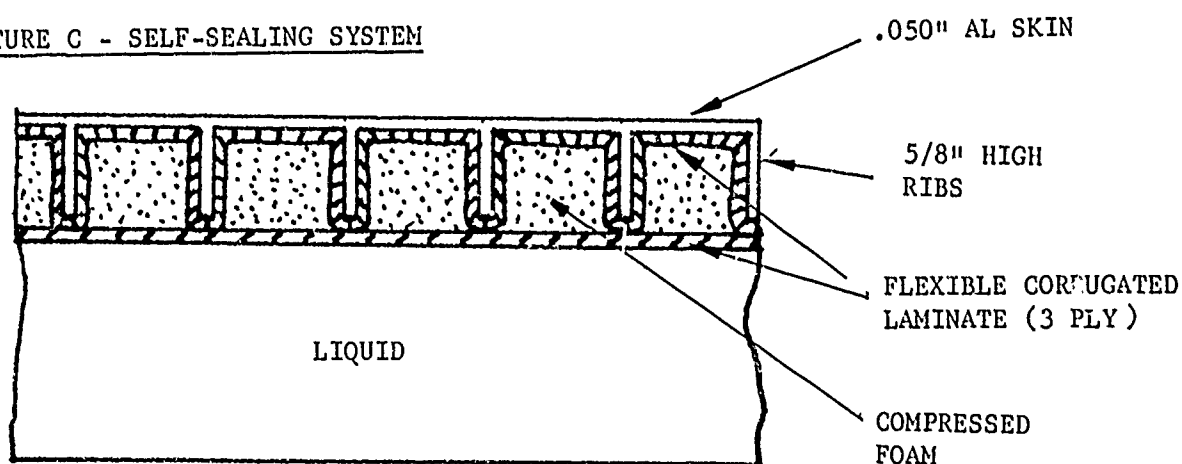


FIGURE 4. C-130 INTEGRAL FUEL TANK WING STRUCTURES



FIGURE 5. C-130 PANELS WITHOUT PROTECTION

Figure 6. At the tank exit side, the tumbling projectile hit the panel between two ribs and left a 1 3/4-inch-long slit in the laminate (Figure 7). The panel skin showed a 2 1/2-inch X 1-inch hole with some petalling (Figure 8). In the case where the projectile hit a rib of the panel at the tank entry side, the rib ruptured and was deformed. The corrugated laminate kept the damage low and reduced the entry hole to the point where it almost sealed. This can be seen in Figures 9 and 10. The panel at the tank exit side was hit by the tumbling projectile which did not penetrate the panel skin. This is illustrated in Figures 9 and 10.

3. C-130 Skin Structure Section Protected with the Damage Control and Self-Sealing Systems

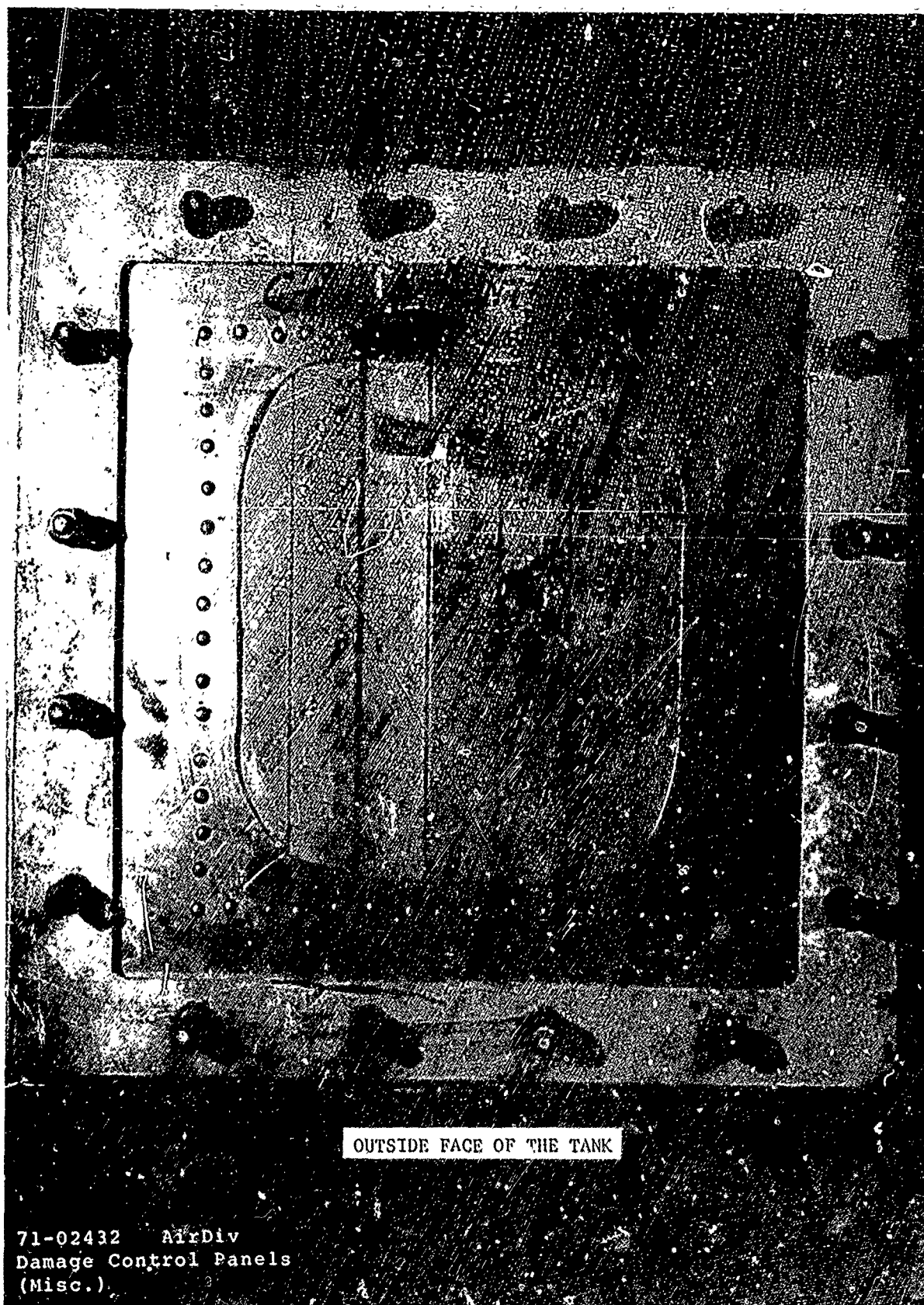
In this series of tests, panels having the configuration of Structure C (Figure 4) were tested at the tank entry side against .50 caliber AP projectiles impacting in either a 90-degree or in a 45-degree angle of incidence. The results obtained in the 90-degree angle of incidence shots are illustrated in Figure 11. Of the fourteen shots which penetrated the panel, ten were between ribs, three brushed the ribs, and one hit one of the ribs. After each impact, immediate sealing was obtained by the combination of the ballistic nylon laminates and the precompressed foam. No rupturing or cracking of the skin was experienced. The liquid loss was insignificant, which showed that the mechanical self-sealing mechanism had worked efficiently. The results obtained in the 45-degree angle of incidence shots are illustrated in Figures 12 and 13. Two 45-degree angle shots were performed in this panel. In a first shot the projectile penetrated between two ribs and hit a rib on its way in. The puncture sealed immediately and no leak was observed. In the second 45-degree angle shot, the projectile hit a rib at entrance. Again efficient sealing was obtained.

Based on the successes obtained above, it was decided to use the self-sealing system illustrated in Figure 4 for installation in the C-130 slosh and vibration test tank and firing test tank.

B. PREPARATION OF C-130 WING TANKS--SLOSH AND VIBRATION TEST TANK AND FIRING TEST TANK

The wing section received from Lockheed, Marietta, was uncrated and mounted on a fixture for disassembly and cutting. All internal plumbing, fuel system components, and trailing edge fairings were removed. The wing section was cut in two places, forming three separate tanks, as shown in Figure 14. Tank number one extended from OWS 214 to OWS 283; tank number two extended from OWS 283 to OWS 421; and tank number three extended from OWS 421 to OWS 562.

Inspection of the number one tank, which initially had been selected for the slosh and vibration test, revealed several cracks in the bottom skin structure. These cracks had apparently occurred during static testing of the wing at Lockheed. Due to the number and size of these cracks, it was deemed inadvisable to use this tank for the slosh and vibration test. This problem was discussed with the AFML. It was agreed that a section (OWS 491 to OWS 562) of number three tank would be used for the slosh and vibration tests.



71-02432 AirDiv
Damage Control Panels
(Misc.)

FIGURE 6. C-130 PANEL WITH DAMAGE CONTROL PROTECTION (ENTRY SIDE)

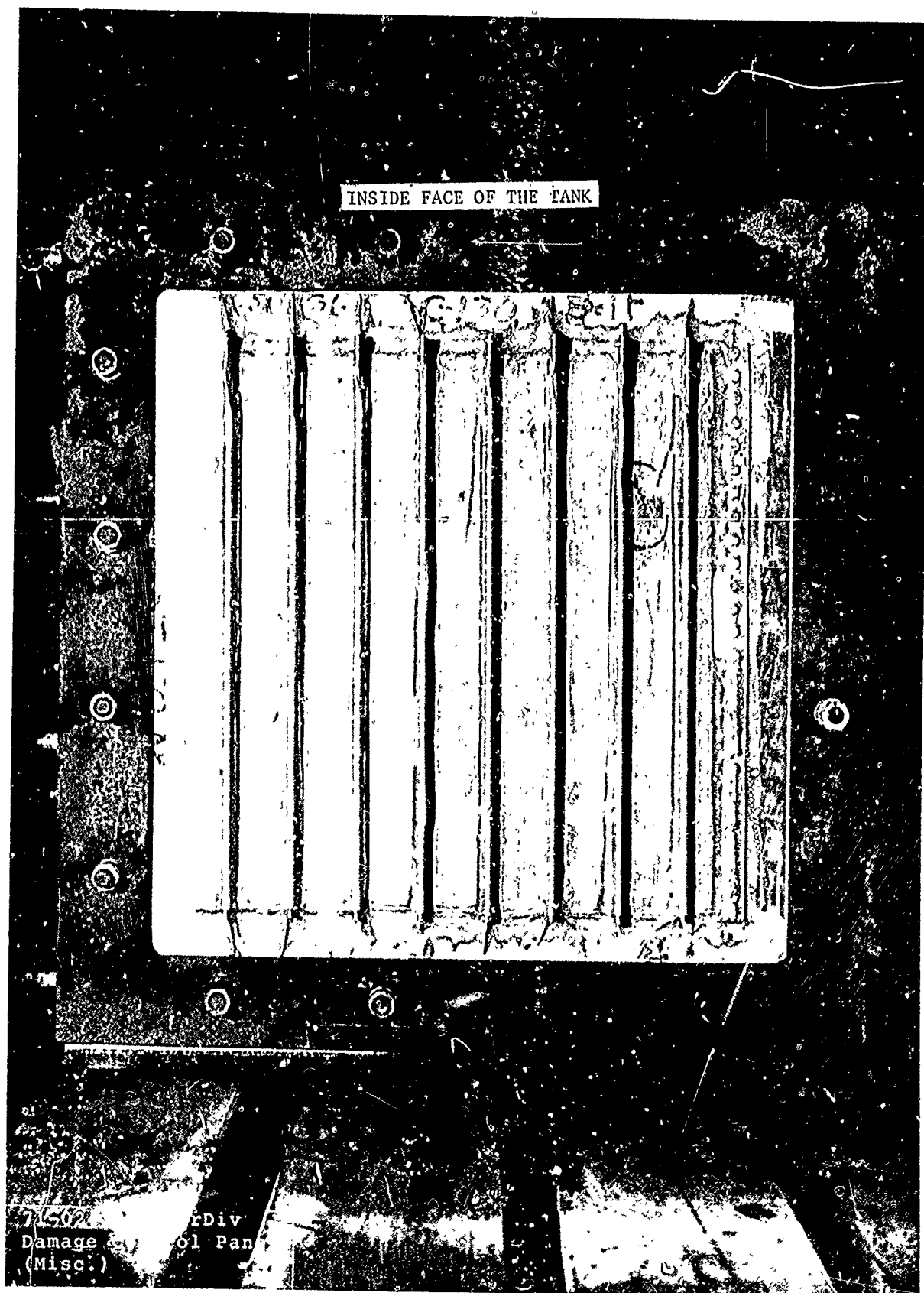


FIGURE 7. C-130 PANEL WITH DAMAGE CONTROL PROTECTION -
EXIT SIDE (INSIDE FACE OF THE TANK)

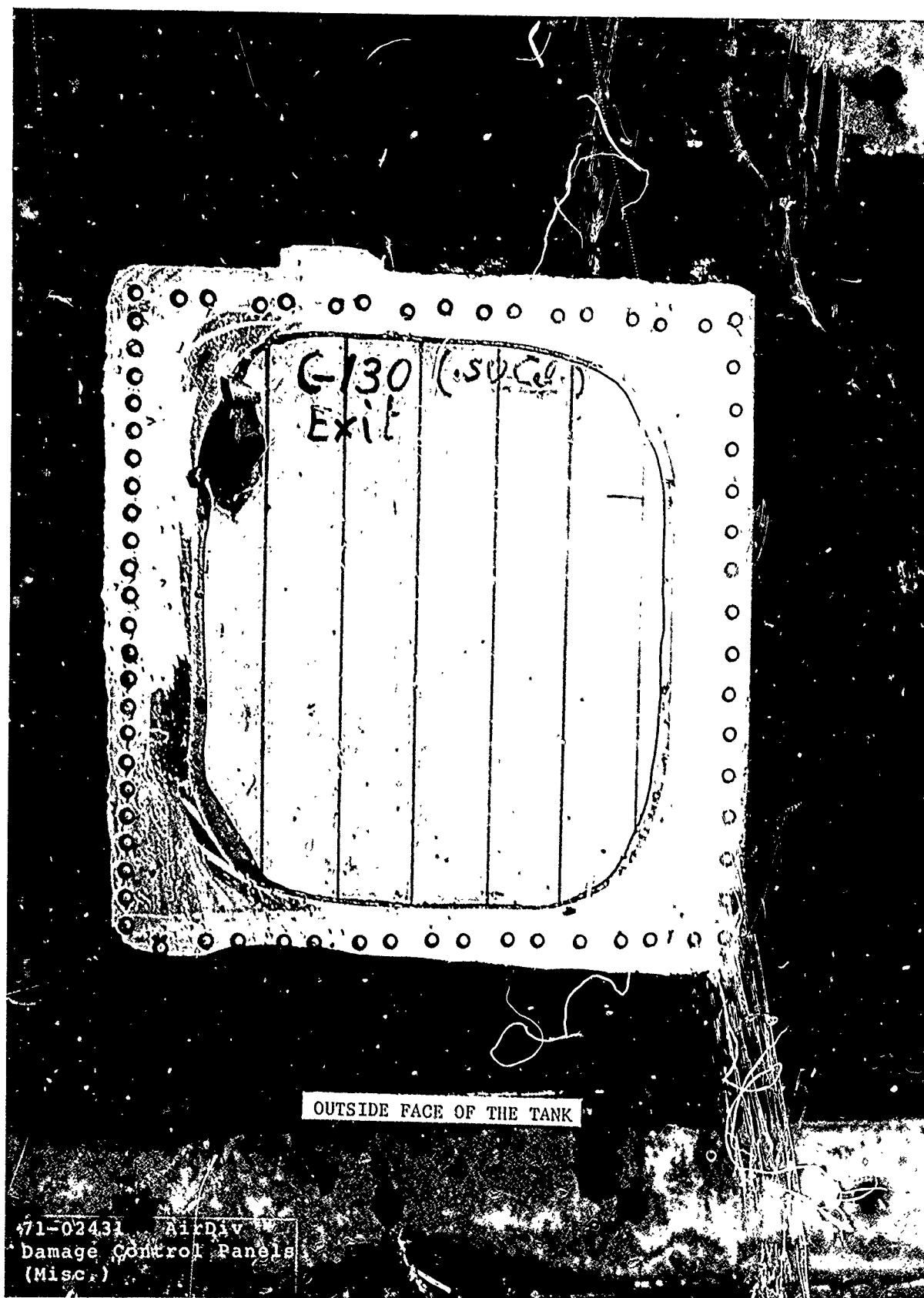


FIGURE 8. C-130 PANEL WITH DAMAGE CONTROL PROTECTION - EXIT SIDE
(OUTSIDE FACE OF THE TANK)

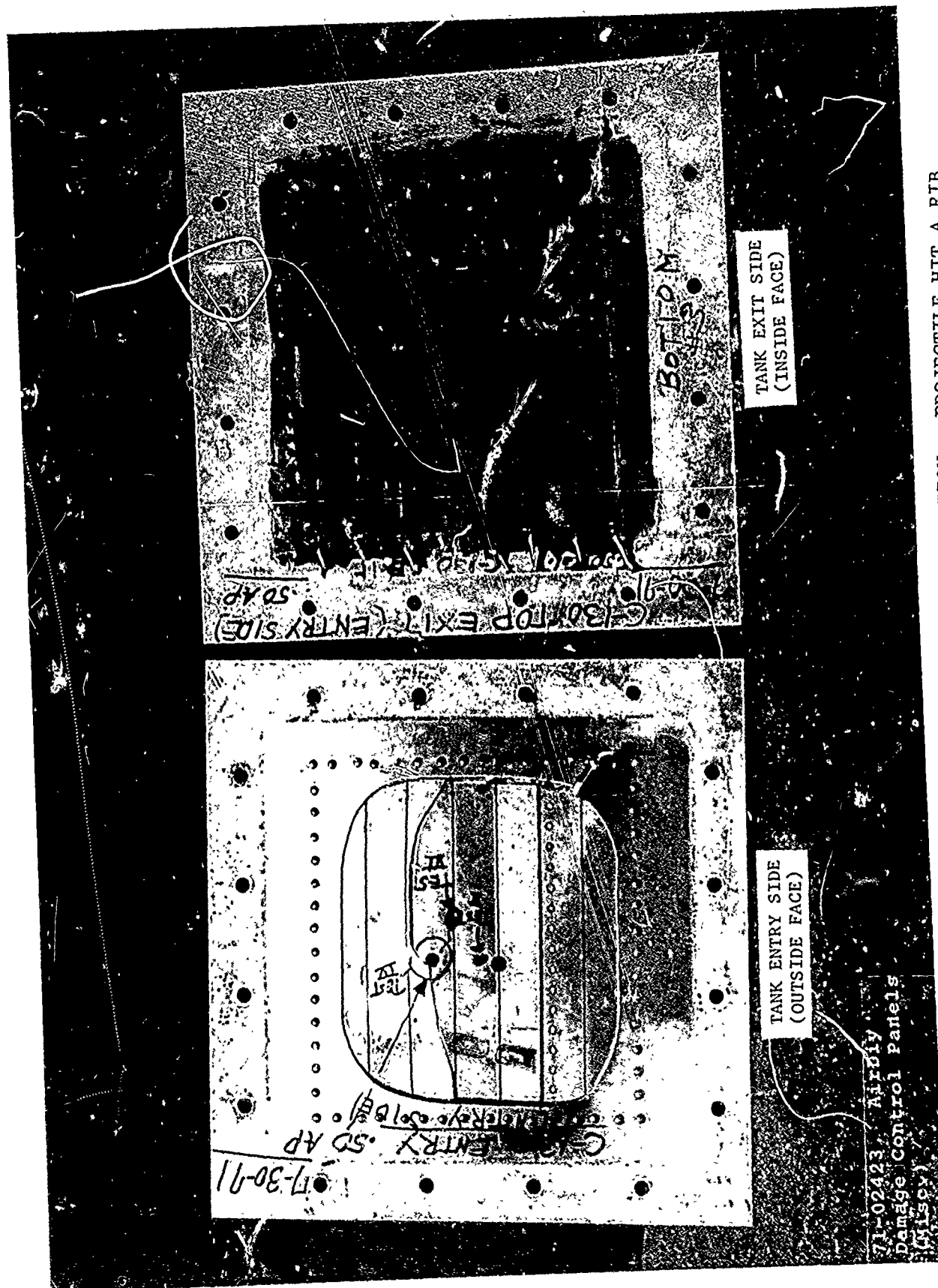


FIGURE 9. C-130 PANEL WITH DAMAGE CONTROL PROTECTION - PROJECTILE HIT A RIB AT ENTRY (OUTSIDE FACE OF ENTRY AND INSIDE FACE OF EXIT ARE SHOWN)



FIGURE 10. C-130 PANEL WITH DAMAGE CONTROL PROTECTION - PROJECTILE HIT A RIB
AT ENTRY (INSIDE FACE OF ENTRY AND OUTSIDE FACE OF EXIT ARE SHOWN)

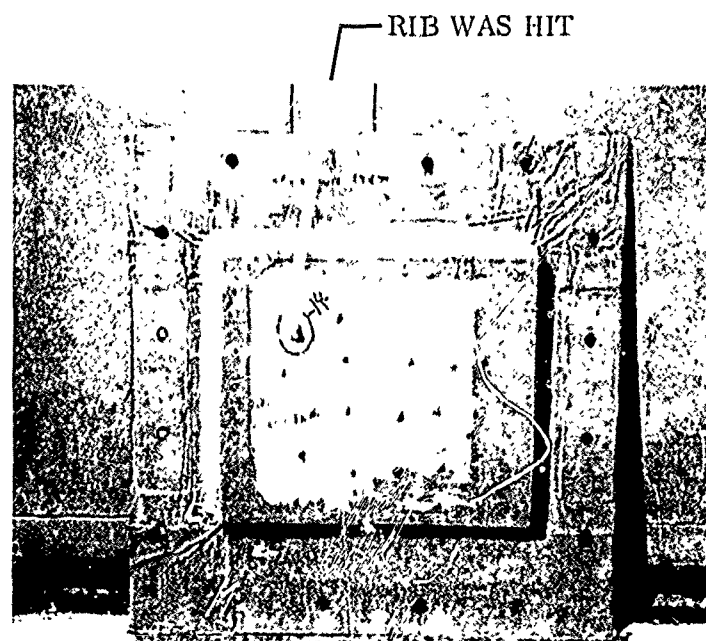
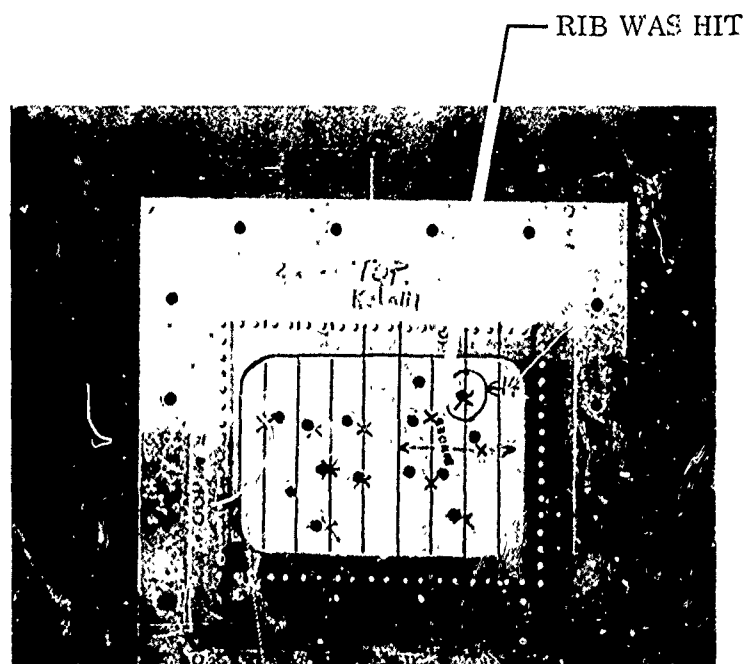


FIGURE 11. C-130 WING PANEL WITH DAMAGE CONTROL AND SELF-SEALING SYSTEMS MOUNTED (90° ANGLE OF INCIDENCE IMPACTS)

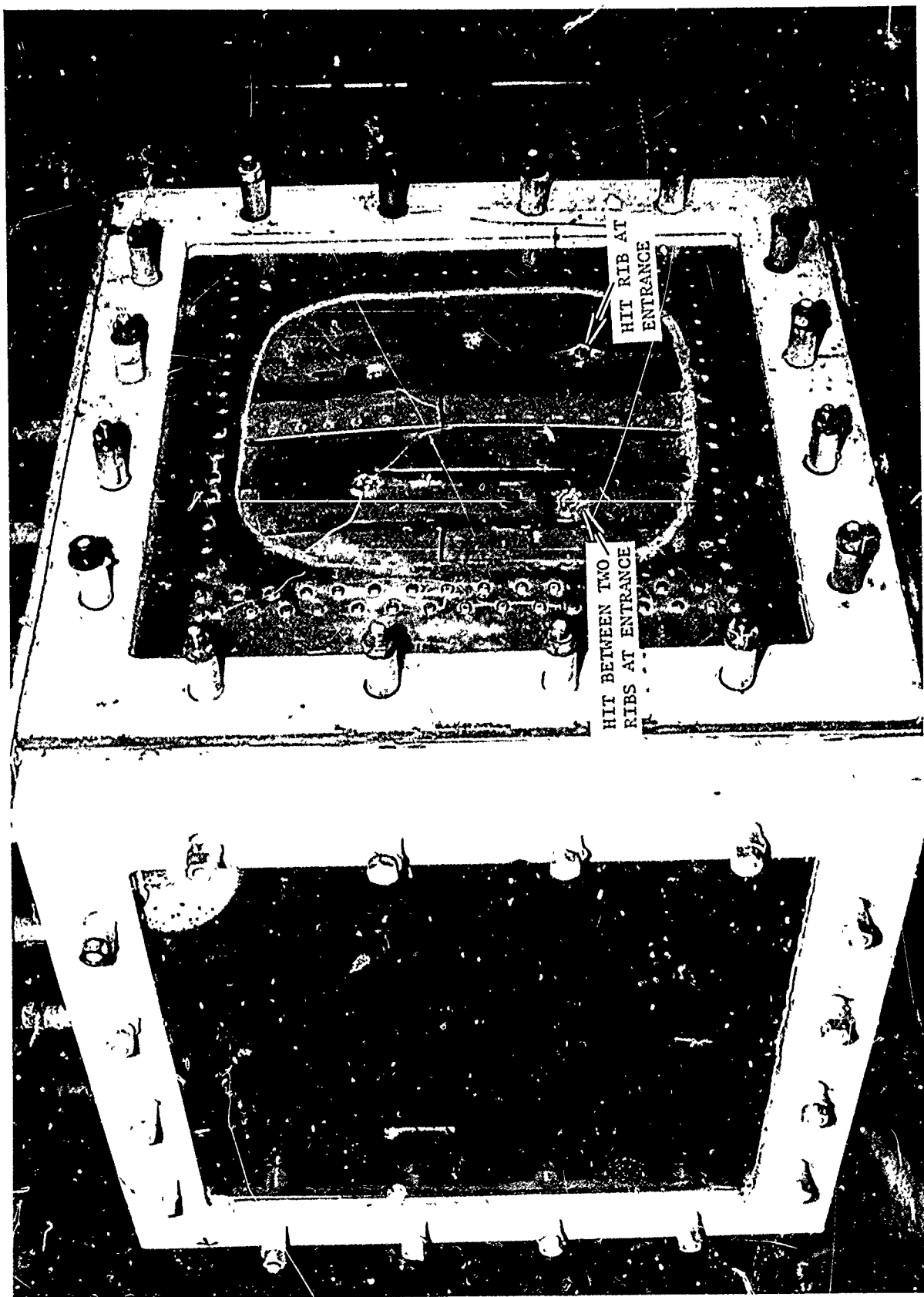


FIGURE 12. C-130 WING PANEL WITH DAMAGE CONTROL AND SELF-SEALING SYSTEMS MOUNTED -
45° ANGLE OF INCIDENCE IMPACTS (OUTSIDE FACE OF ENTRY PANEL)

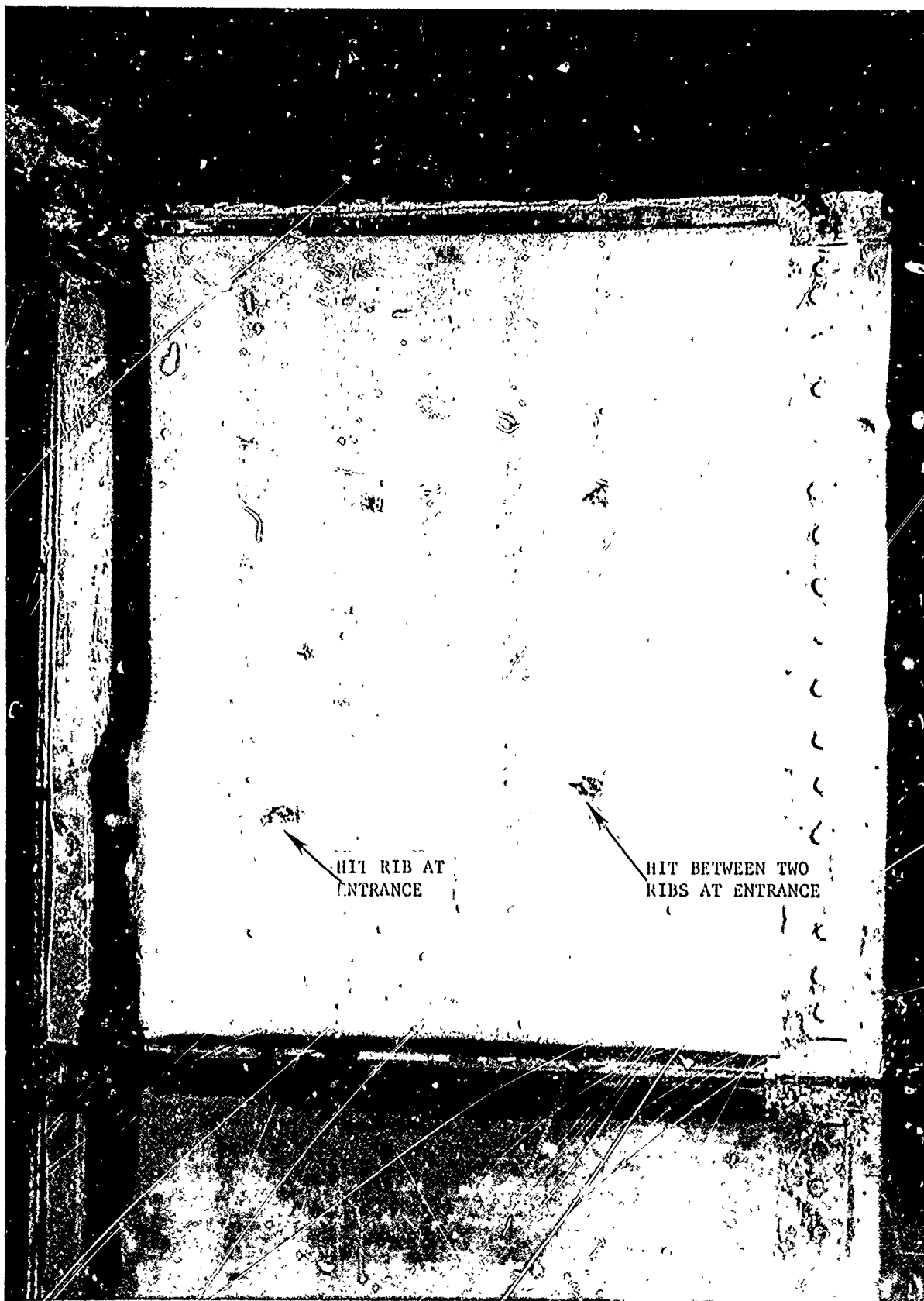


FIGURE 13. C-130 WING PANEL WITH DAMAGE CONTROL AND SELF-SEALING SYSTEMS MOUNTED - 45° ANGLE OF INCIDENCE IMPACTS (INSIDE FACE OF ENTRY PANEL)

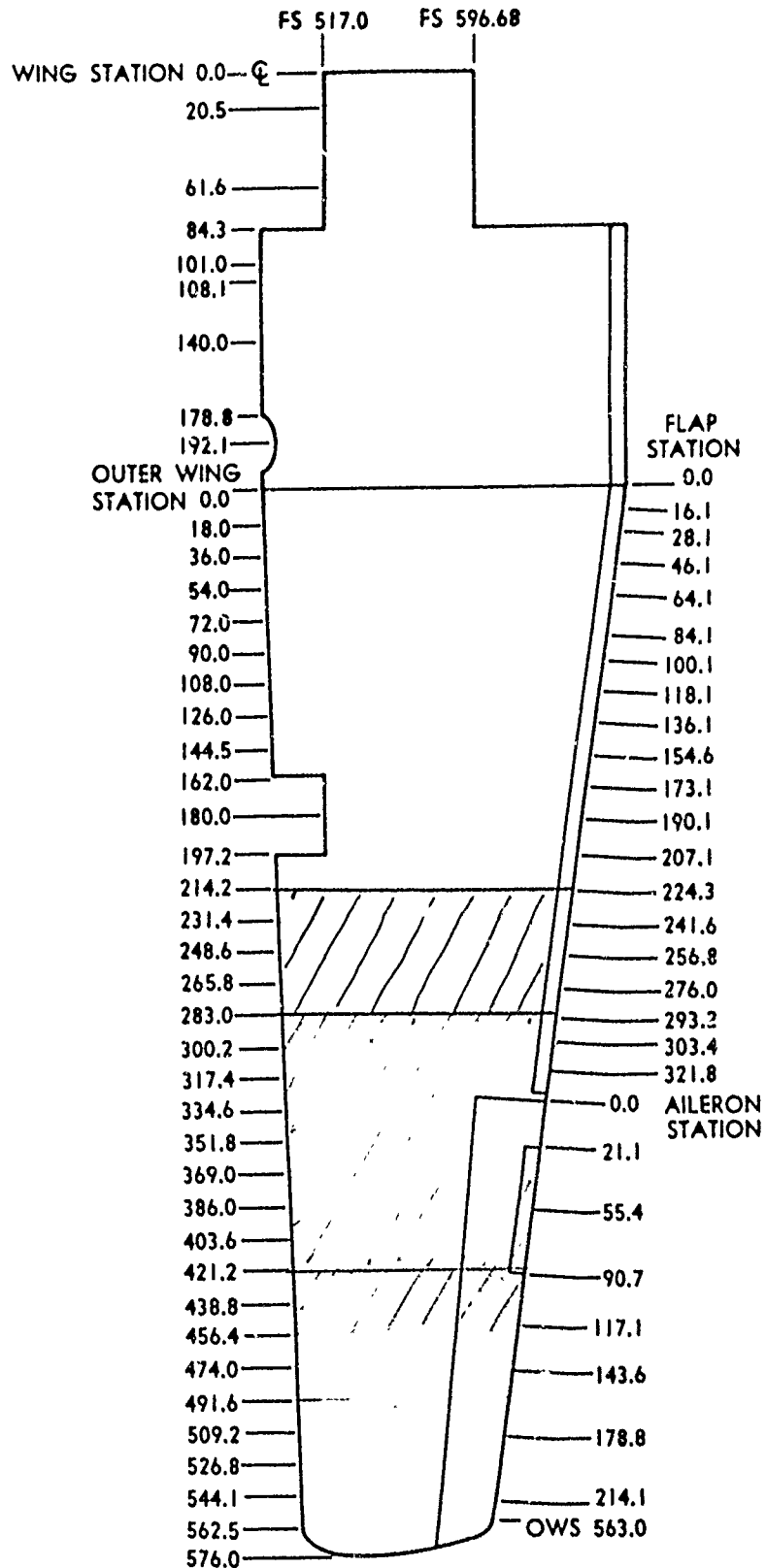


FIGURE 14. AIRPLANE WING STATIONS

Figure 15 shows this particular section. The other section (OWS 421 to OWS 491) of the number three tank was cut up for use in evaluating methods for attachment of the damage control and self-sealing systems, for preliminary firing tests, and for preparing a mold to be used in the fabrication of the corrugated laminates. The skin thickness of section OWS 491 to OWS 562 varied from .050 to .040-inch and the rib thickness measured 1/16-inch.

Closeout bulkheads, plates and stiffeners were fabricated and assembled into the number three tank to seal off the ends. The tank was checked with water pressure and visible leaks were sealed.

Closeout plates, clips and stiffeners were fabricated and installed into the number two tank (OWS 283 to OWS 421) to seal off the ends and holes left after removal of the fuel system components. This tank, which was used for the firing tests, is shown in Figure 16. The skin thickness of this tank varied from .050 to .064 inch and the rib thickness measured from 1/16 to 3/32 inch.

Prior to installation of the self-sealing system in the slosh and firing tanks, several loose parts such as ribs of vertical trusses and rivets at the bottom skin structure were noted. These defects apparently occurred during static testing of the wing at Lockheed.

C. FABRICATION OF DAMAGE CONTROL AND SELF-SEALING SYSTEMS AND THEIR INSTALLATION IN THE C-130 SLOSH AND VIBRATION TEST TANK

1. Fabrication of the Corrugated Laminate (Damage Control System) for the Symmetrical Sections of the Tank Bays

A method for fabricating the flexible corrugated ballistic nylon laminates was developed. In the method which showed most promise, the laminate was prefabricated using a C-130 wing skin section as a mold. The mold, which was used for the fabrication of the corrugated flexible laminates to be installed in the slosh and vibration test tank, was obtained by dismantling the bottom C-130 skin structure of the wing station OWS 456 to OWS 491. Figure 17 shows this particular mold. Using this mold, the following materials, equipment, and procedure were used for the fabrication of four-ply corrugated laminates.

Materials and Equipment Used:

- a. Ballistic nylon cloth--four layers per laminate (14 oz./linear yard)
- b. Coast Pro-Seal 898 polysulfide sealant (two parts)
- c. Methylethylketone (MEK) for diluting the 898 sealant
- d. Non-porous and porous Teflon impregnated glass cloth
- e. Metal bars for the molding operation
- f. Mold (1 1/2 feet wide X 4 feet long)
- g. Clamps for clamping the metal bars against the wet laminate between the mold ribs
- h. Bleeder material (Osnaburg cloth)
- i. Heat sealable plastic bags
- j. Autoclave

Procedure Used

- a. Cut ballistic nylon cloth into four equal pieces, 20 inches X 96 inches.
- b. Prepare the diluted Coast Pro-Seal 898 sealant solution. Mix 100 parts (by weight) of 898 sealant with 10 parts (by weight) of sealant accelerator and 15 parts (by volume) MEK. Thoroughly mixed, this mixture gives a liquid sealant of sufficient low viscosity to efficiently permeate through the ballistic nylon.



FIGURE 15. C-130 SLOSH AND VIBRATION TEST WING TANK

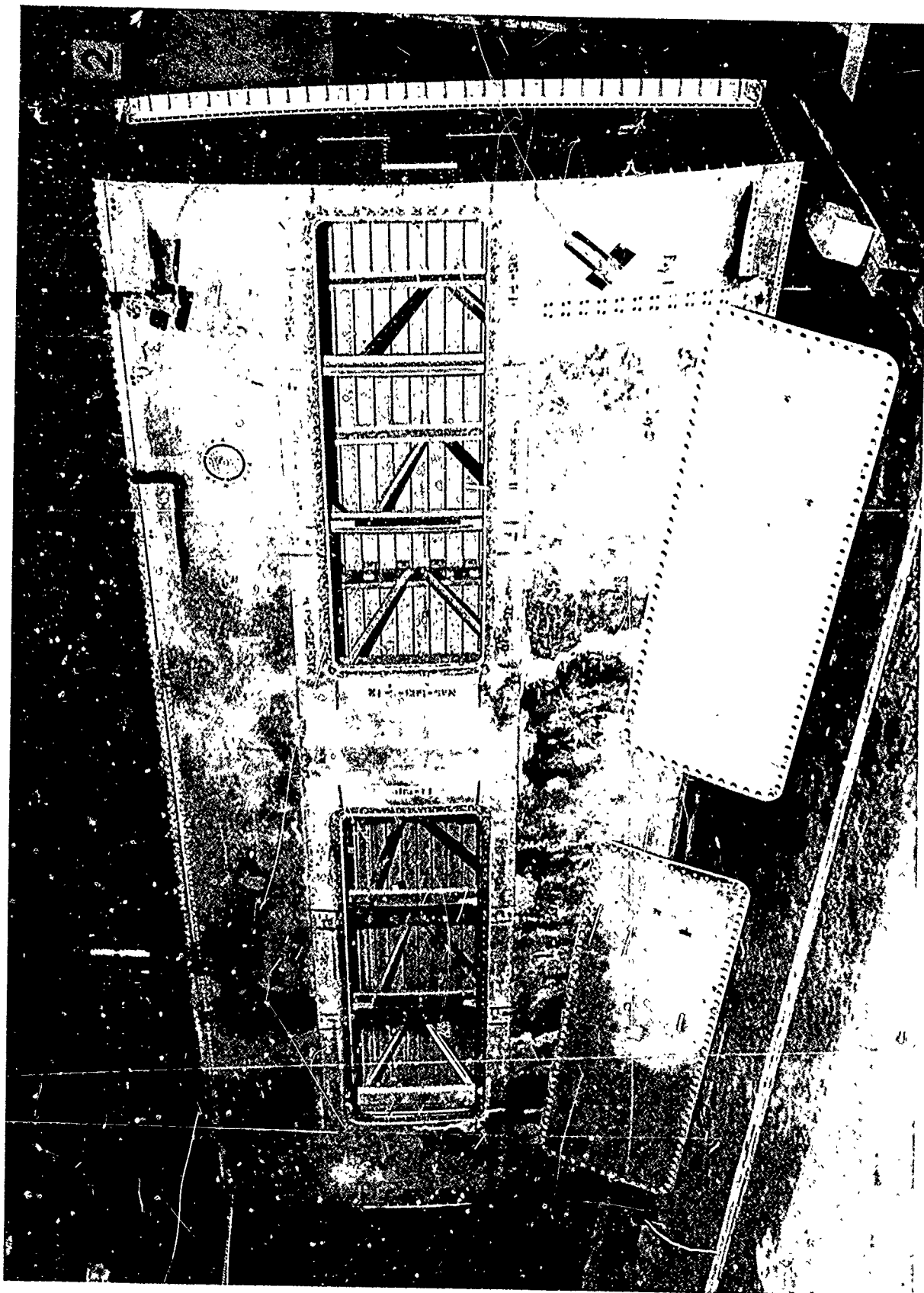


FIGURE 16. C-130 FIRING TEST WING TANK

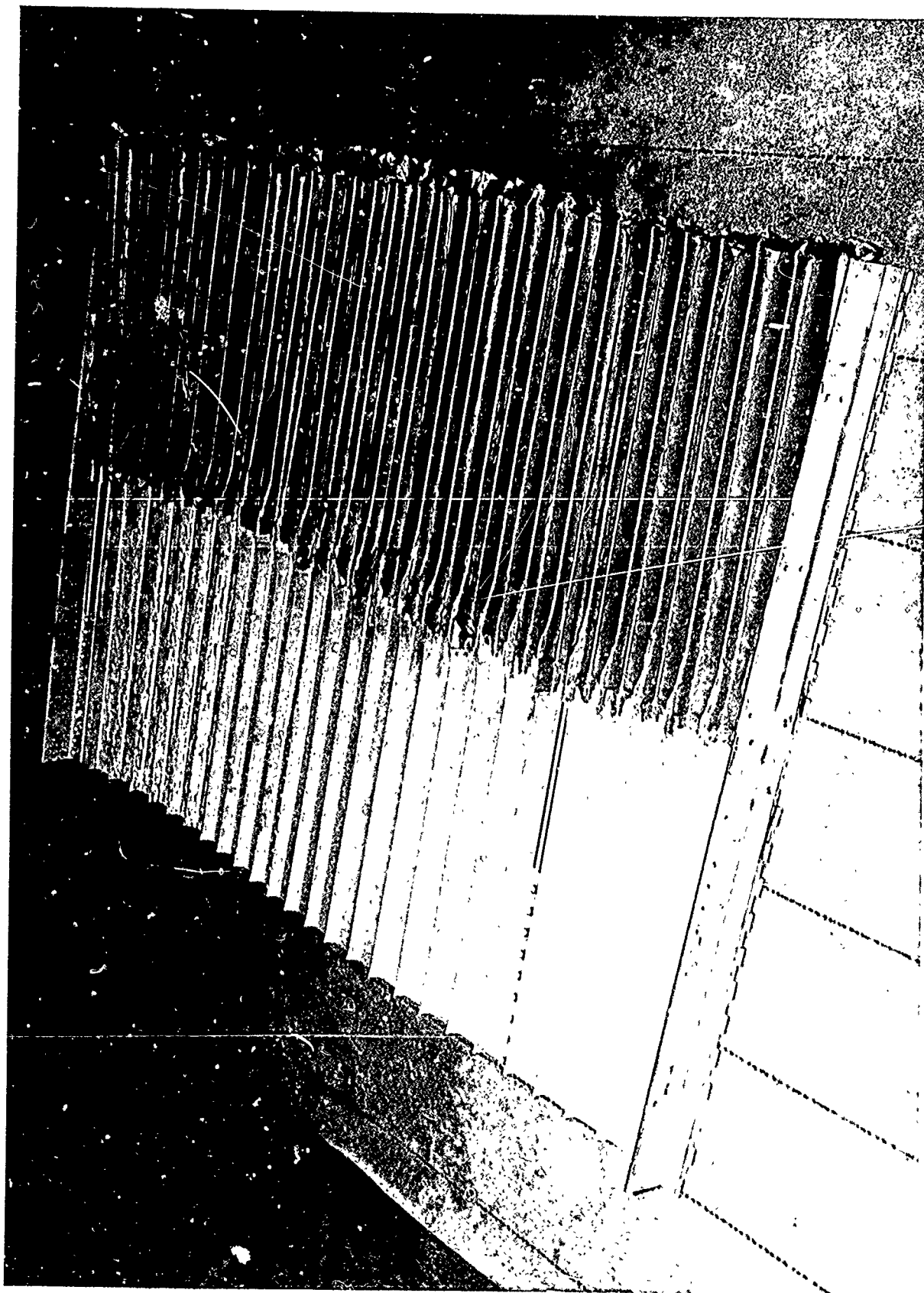


FIGURE 17. C-130 WING SKIN SECTION USED AS A MOLD

- c. Impregnate the cut ballistic nylon cloth layers with the prepared low viscosity sealant. The first ballistic nylon layer is placed on top of a piece of Teflon impregnated glass cloth, which is used as a mold release. The exposed side of the ballistic nylon cloth is then impregnated with the low viscosity sealant. (Fig. 18). This partially impregnated ballistic nylon cloth is then turned over and again impregnated with the sealant. The second layer of ballistic nylon cloth is then placed on top of the first sealant impregnated layer. The exposed side of the second layer is impregnated with the sealant material. The same procedure is continued with the third and fourth ballistic nylon layers. When the four layers are sandwiched together, a piece of porous Teflon impregnated glass cloth is placed on top of the last ballistic nylon cloth layer. The purpose of a porous type material here is to allow release of trapped gas bubbles when the impregnated ballistic nylon layers are exposed to the high pressures during the cure.
 - d. Fit the lay-up of wet ballistic nylon cloth layers to the mold. This is accomplished, as shown in Figures 19 and 20, with metal bars (wrapped in Teflon impregnated glass cloth for release purposes) and clamps. As shown in the figures, the metal bars push the wet ballistic nylon layers snug against the mold between the ribs. The clamps are used to keep the bars tight and to prevent the bars from moving out of their positions between the ribs. A total of 52 clamps was needed to fit the total length of the wet laminate to the four-foot-long mold. The rib height and the rib spacing of this particular mold were $5/8$ inch and $1\ 3/4$ inch respectively.
 - e. Bag the mold containing the wet molded laminate. A heat sealable plastic bag is used for the bagging. In the bagging operation (see Figure 21), the following steps are necessary: (a) remove the clamps, (b) wrap the mold in bleeder material (Osnaburg cloth), (c) place the wrapped mold in a plastic bag which is heat sealed, and (d) pull a vacuum.
 - f. Cure the polysulfide sealant. The bagged mold under vacuum is placed in the autoclave. A pressure of approximately 35 to 40 psi and a temperature of approximately 180°F are applied inside the autoclave. These conditions are held for $1\ 1/2$ hours. A cooling time of approximately $1/2$ hour is allowed before opening the autoclave and removing the mold with the cured corrugated laminate. Figure 22 shows the cured and completed laminate. This procedure for fabricating corrugated laminates with the above mold, was used for preparing four similar corrugated laminates for installation in the slosh and vibration test tank.
2. Fabrication of the Corrugated Laminates (Damage Control System) for the Asymmetrical Sections of the Tank Bays

As can be seen in Figures 15 and 16, which show the slosh and vibration test tank and the firing test tank, one side of each tank is tapering off as one proceeds in the outboard direction. The other side remains straight or untapered. On the untapered side, the corners, from one bay to the next,



FIGURE 18. IMPREGNATION OF THE BALLISTIC NYLON CLOTH
WITH LOW VISCOSITY SEALANT



FIGURE 19. FITTING THE WET BALLISTIC NYLON
LAMINATE TO THE MOLD - METAL BARS



FIGURE 20. FITTING THE WET BALLISTIC NYLON LAMINATE TO THE MOLD -
A CLAMPING SYSTEM IS USED FOR OBTAINING A BETTER
QUALITY LAMINATE



FIGURE 21. BAGGING OF MOLD

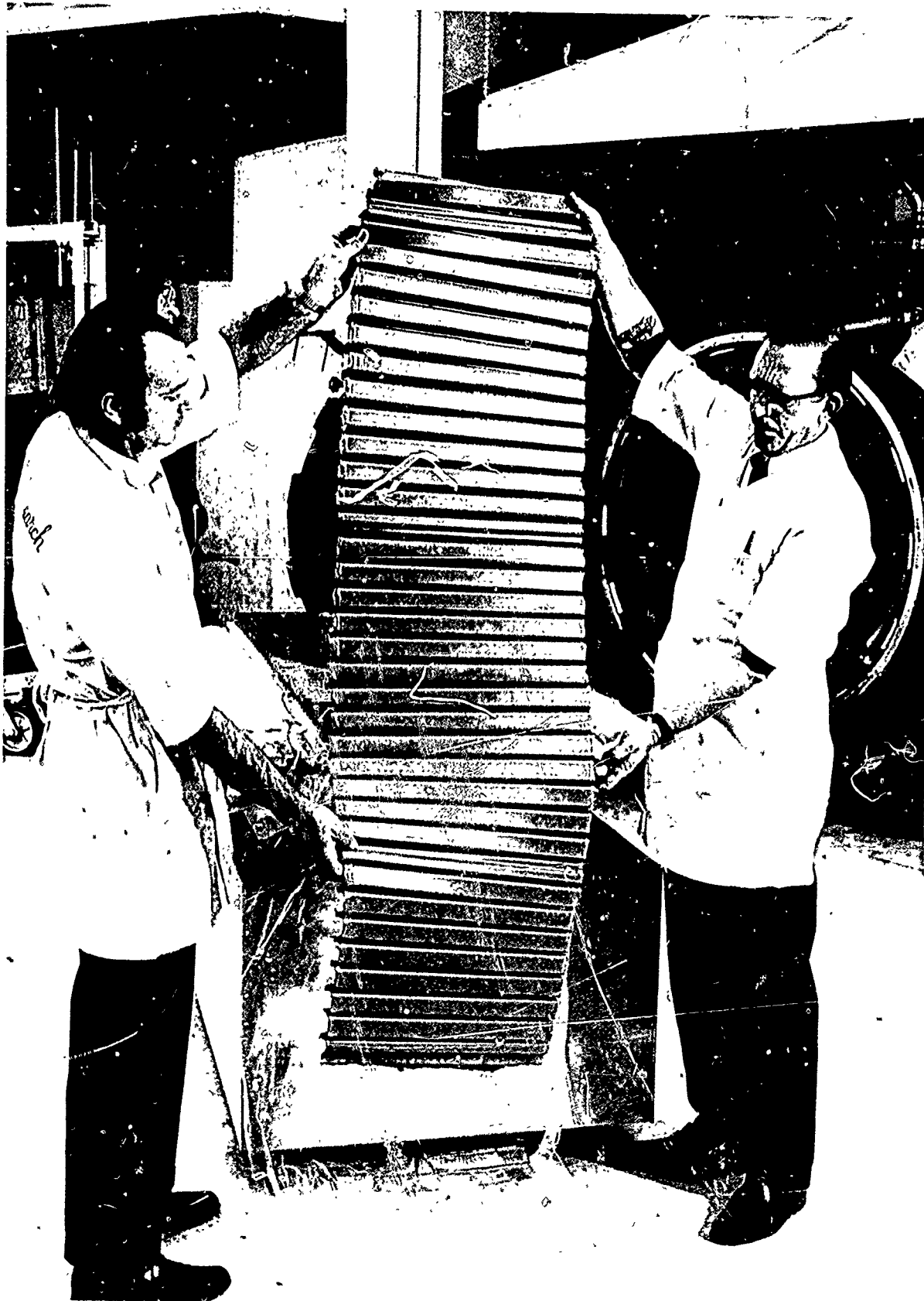


FIGURE 22. A FINISHED CORRUGATED LAMINATE IS SHOWN

are symmetrical or alike. However, on the tapered side, the corners, from one bay to the next, are not alike; they are asymmetric. For fabricating the corrugated laminates to be installed in these asymmetrical corner-sections, a special mold had to be fabricated for each bay of the two tanks. An example of such a special mold is illustrated in Figure 23. The procedure for fabricating the corrugated laminates, using these special molds, was similar to the one described above. Figure 24 shows one of the completed corner-section laminates usable only for the corner of one specific bay of the tanks. Ten different molds were fabricated for preparing three corner laminates for the slosh and vibration test tank and seven for the firing test tank.

3. Installation of the Corrugated Laminates at the Bottom Part of the Slosh and Vibration Test Tank

The prepared corrugated laminates were cut to fit the symmetrical and asymmetrical sections of the tank bays. As is depicted in Figure 2, the bays in question were OWS 491 to 509, OWS 509 to 526 and OWS 526 to 544. The bay OWS 544 to 562 was left without any protection. The technique used to bond the laminates to the bottom of each of the three bays consisted of three major steps. Step one was to brush MEK diluted 898 sealant onto the MEK cleaned surface where the laminates were to be bonded. Step two was to install the MEK cleaned laminates to the bonding area and apply pressure against the laminates by means of a series of turn barrels inserted inside the tank between the top section of the tank and the laminates at the bottom section of the tank, as shown in Figures 25 and 26. The asymmetrical corrugated corner laminate and the symmetrical corrugated laminate were made to overlap at an area between two ribs. To apply a uniform pressure across the laminates and obtain a uniform bonding at all points of the laminates, special wooden blocks that fit snugly between each two ribs were used (Figure 27). To simplify the setting up of the turn barrels and to obtain a more uniformly distributed pressure across the laminate, large metal plates were placed on top of the wooden blocks as shown in Figure 28. Step three was to cure the 898 bonding material. This was performed by rolling the tank into a large oven and heating to 180°F for 1 1/2 hours. A 1/2 hour was allowed for cooling off the system to room temperature. After removal of the turn barrels, metal plates and wooden blocks, inspection showed an excellent and uniform bond of the laminates was obtained (Figure 29).

4. Installation of the Precompressed Foam (Self-Sealing System) at Bottom Section of the Slosh and Vibration Test Tank

As illustrated in Figure 4, the precompressed foam, which is located between the ribs of the C-130 skin structure, is the self-sealing part of the self-sealing materials system. To put the foam in a compressed state, the foam strips were cut oversize and forced between the ribs. Besides providing seals, the foam also helps by absorbing the hydraulic ram pressure to reduce damage to the C-130 skin structure. The type foam used was the Buna-N (Nitrile) base, oil and aromatic fluid resistant medium cellular rubber.

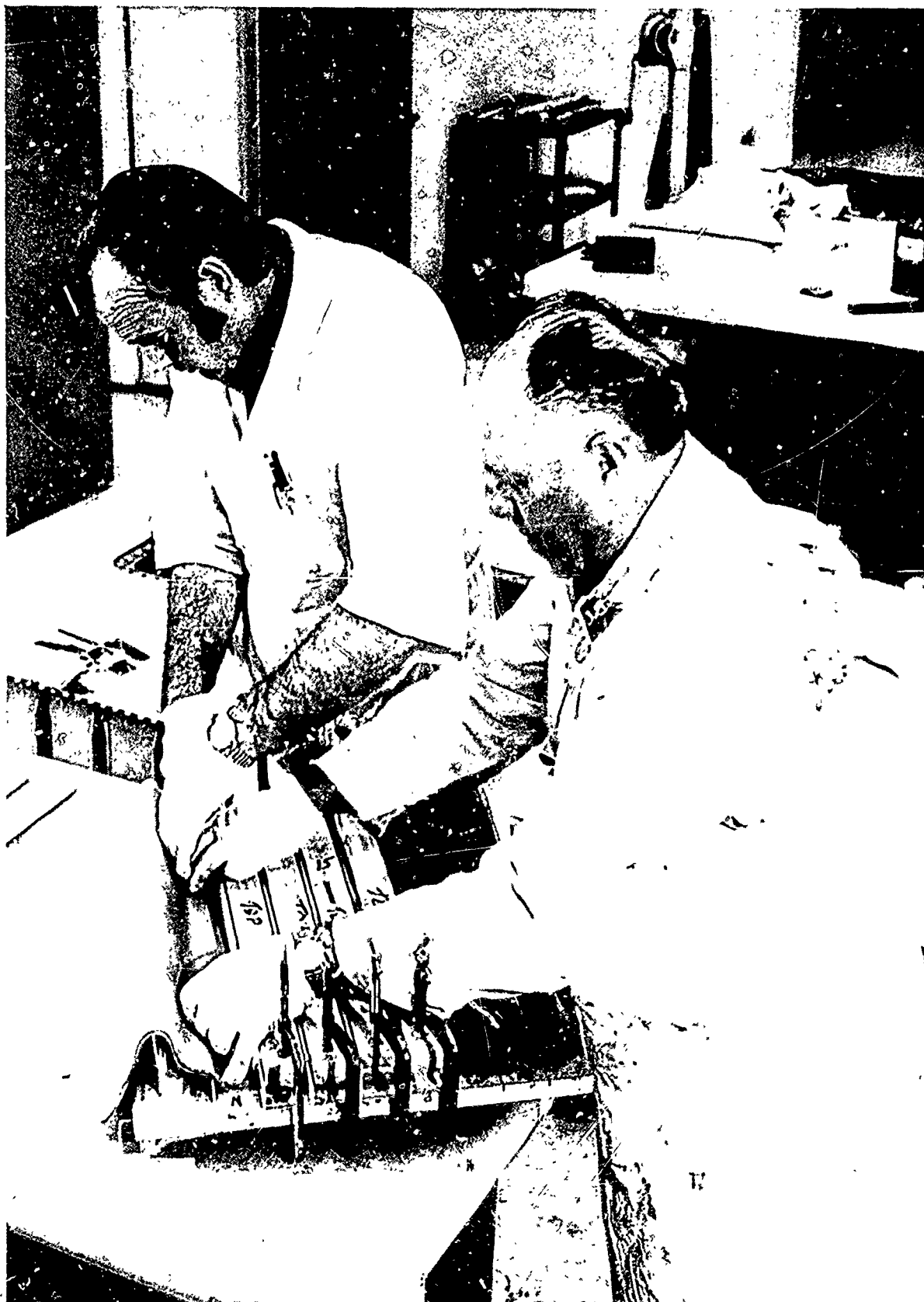


FIGURE 23. MOLD USED FOR THE ASYMMETRICAL SECTIONS
OF THE TANK BAYS



FIGURE 24. COMPLETED CORNER - SECTION LAMINATE

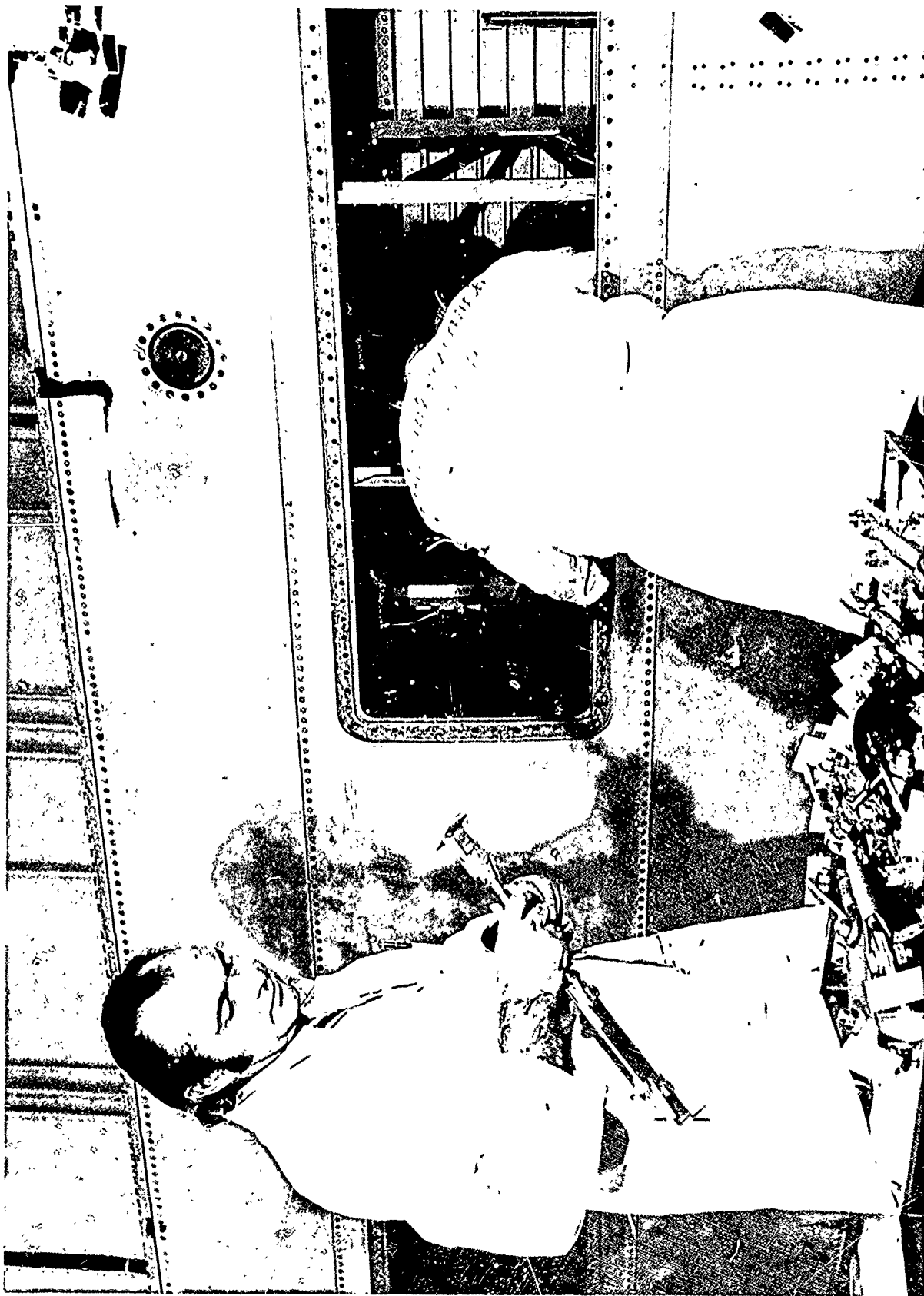


FIGURE 25. INSTALLATION OF THE CORRUGATED LAMINATE USING
TURN-BARRELS FOR PRESSURE APPLICATIONS



FIGURE 26. INSTALLATION OF THE CORRUGATED LAMINATE - TURN-BARRELS
PUT IN PLACE IN TANK BAY

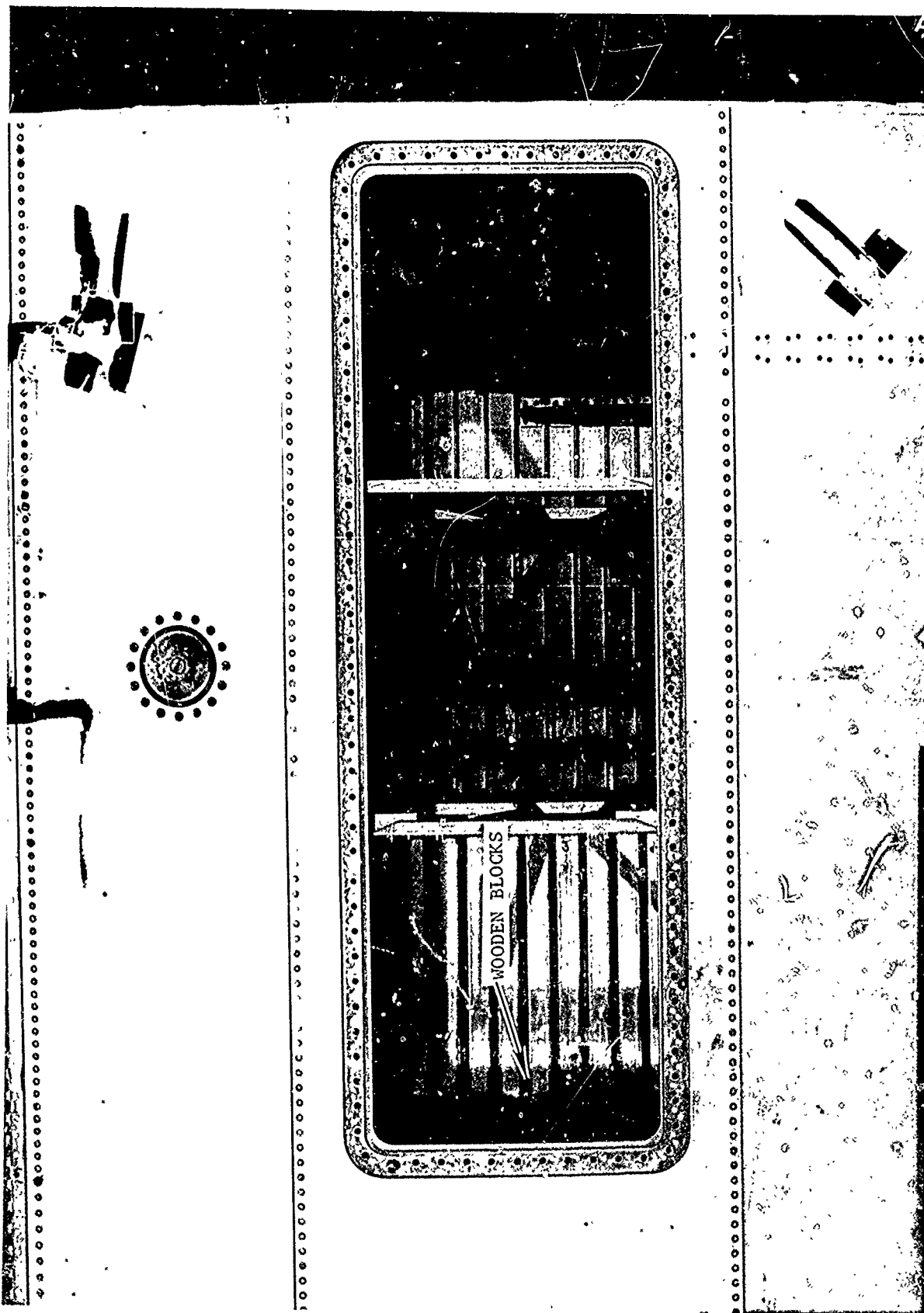


FIGURE 27. SPECIAL WOODEN BLOCKS INSERTED BETWEEN THE RIBS

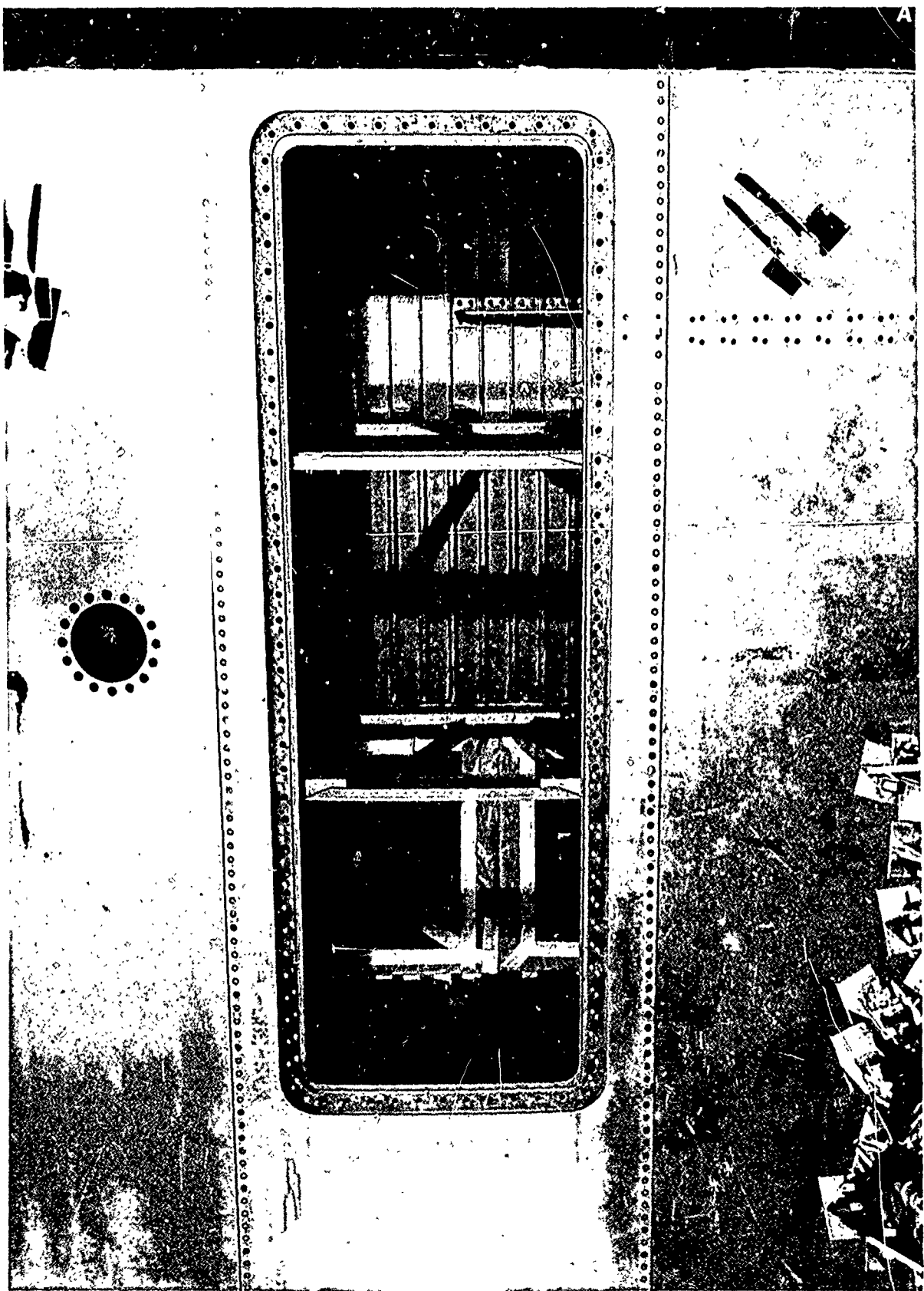


FIGURE 28. LARGE METAL PLATES USED TO OBTAIN A MORE UNIFORM PRESSURE

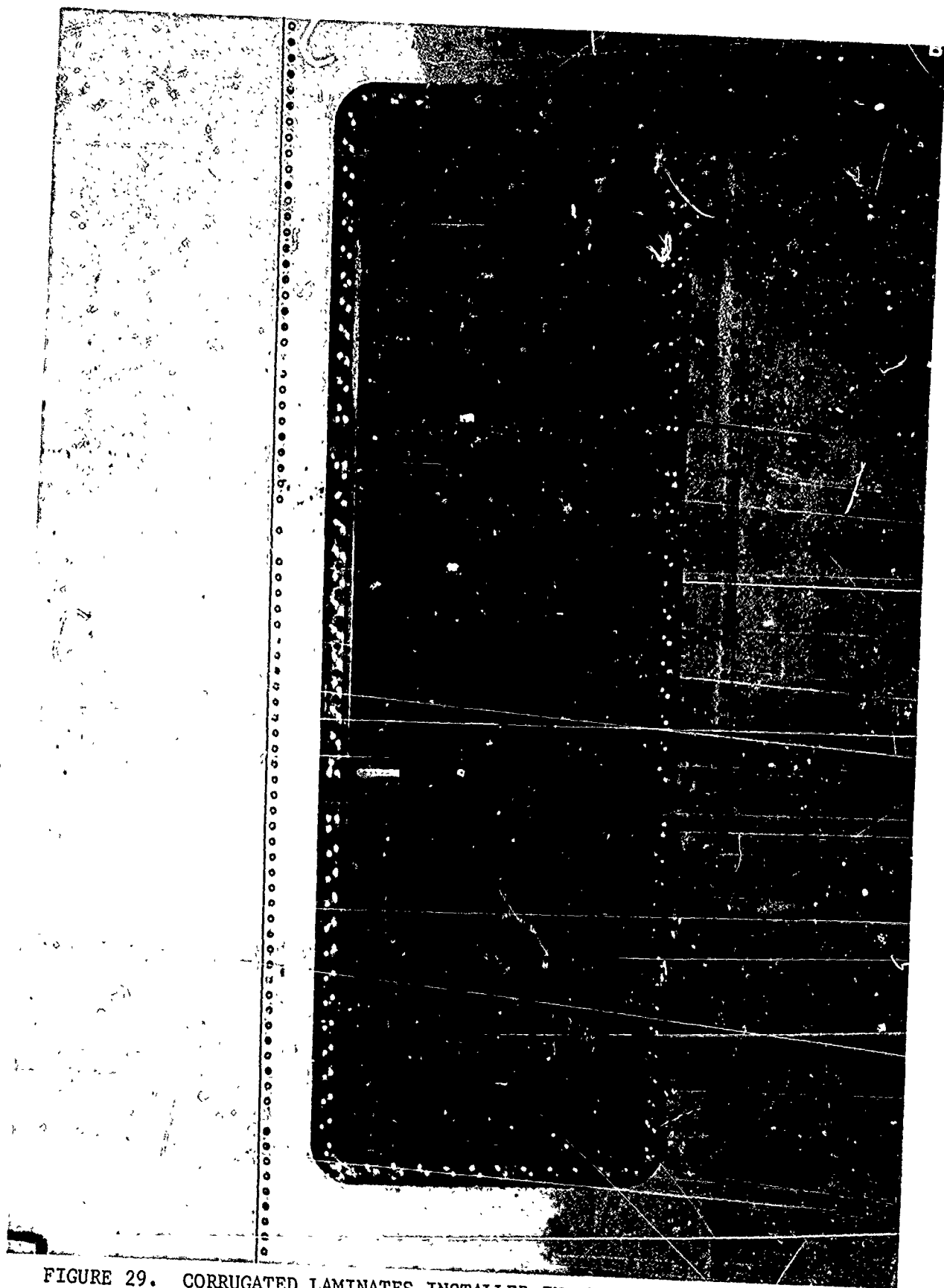


FIGURE 29. CORRUGATED LAMINATES INSTALLED IN THREE BAYS OF THE TANK

For the installation of the foam in the slosh and vibration test tank, strips of foam 1 3/4-inch wide and 5/8-inch high were cut. At the bottom part of the tank, the rib spacing was 1 1/2 inch and the height of the ribs 5/8-inch. After installation of the foam strips, the degree of precompression of the foam was approximately 15%. In the actual installation, the foam was squeezed in between the ribs and bonded on all three sides and at the ends with 898 sealant as shown in Figure 30. A uniform pressure was applied by means of metal plates and turn barrels. The curing of the sealant was performed in a large oven at 180°F for 1 1/2 hours. Figure 31 shows the precompressed foam installed in all three bays of the tank.

5. Fabrication of the Plain Flat Laminates

Four-ply plain flat laminates were fabricated using a procedure similar to that for the fabrication of the corrugated laminates described above. A flat metal plate was used as the mold, and this eliminated the metal bars and the clamps. The curing pressure was 50 psi; the curing temperature was 180°F for 1 1/2 hours and the cooling time after cure was 1/2 hour. A sample of a finished plain laminate is illustrated in Figure 32. It measures 20 inches X 72 inches. A total of nine such laminates was prepared. Three were used for the slosh and vibration test tank and six for the firing test tank.

6. Installation of Plain Laminates in Slosh and Vibration Test Tank

Three of the above fabricated plain flat laminates were cut to fit snugly in each of the three bays. The bonding of the laminates in each bay to the compressed foam and ribs was performed using metal plates and turn barrels to obtain uniform pressure and using 898 sealant as the bonding agent (Figure 33). The curing of the sealant was accomplished by placing the tank in the large oven and heating at 180°F for 1 1/2 hours.

After installation of the plain flat laminates, to assure a good seal of the laminates to each other and to the metal tank, beads of 898 sealant were put along the edges of the laminates using the sealant gun. Figure 34 shows the slosh and vibration tank completed with damage control and self-sealing systems installed and ready for the slosh and vibration test. The total weight of the installed system was 1.70 pounds/foot². The thickness of the system exceeded the height of the structural ribs (5/8-inch) by 3/16 of an inch.

D. FABRICATION OF DAMAGE CONTROL (BOTTOM AND TOP SECTIONS OF TANK) AND SELF-SEALING SYSTEMS (BOTTOM SECTION ONLY) AND THEIR INSTALLATION IN THE C-130 FIRING TEST TANK

The fabrication of the four-ply corrugated laminates for the firing test tank bays, bottom sections OWS 283 through OWS 403 (see Figure 2), was performed in a manner similar to the fabrication of the corrugated laminates for the slosh and vibration test tank (see Section C above). The only exception was that the mold used for the slosh and vibration test tank had to be modified slightly. The ribs had to be increased in height from 5/8-inch



FIGURE 30. INSTALLATION OF THE PRECOMPRESSED FOAM IN TANK BAYS

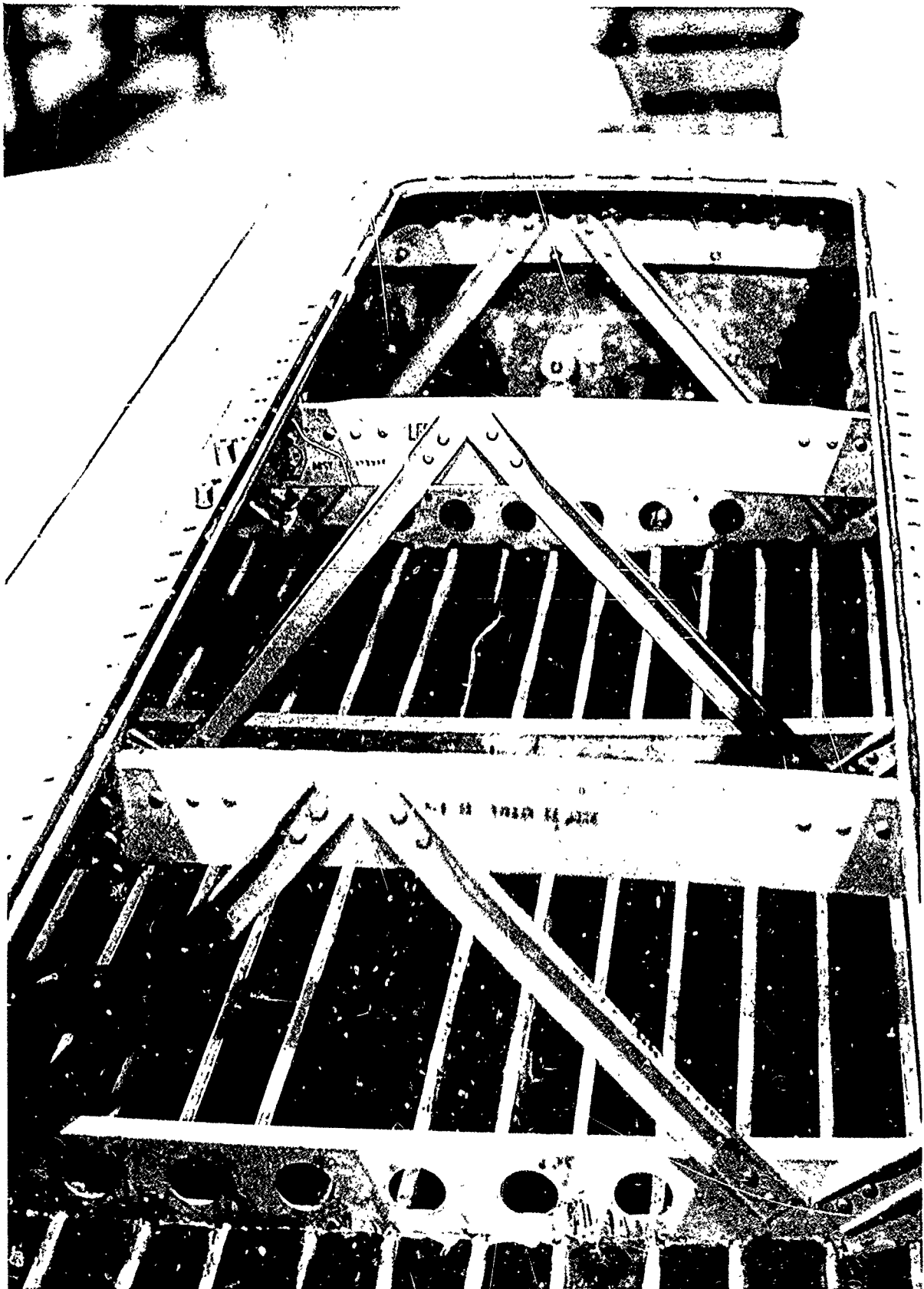


FIGURE 31. TANK BAYS WITH PRECOMPRESSED FOAM INSTALLED



FIGURE 32. A COMPLETED PLAIN FLEXIBLE LAMINATE IS SHOWN

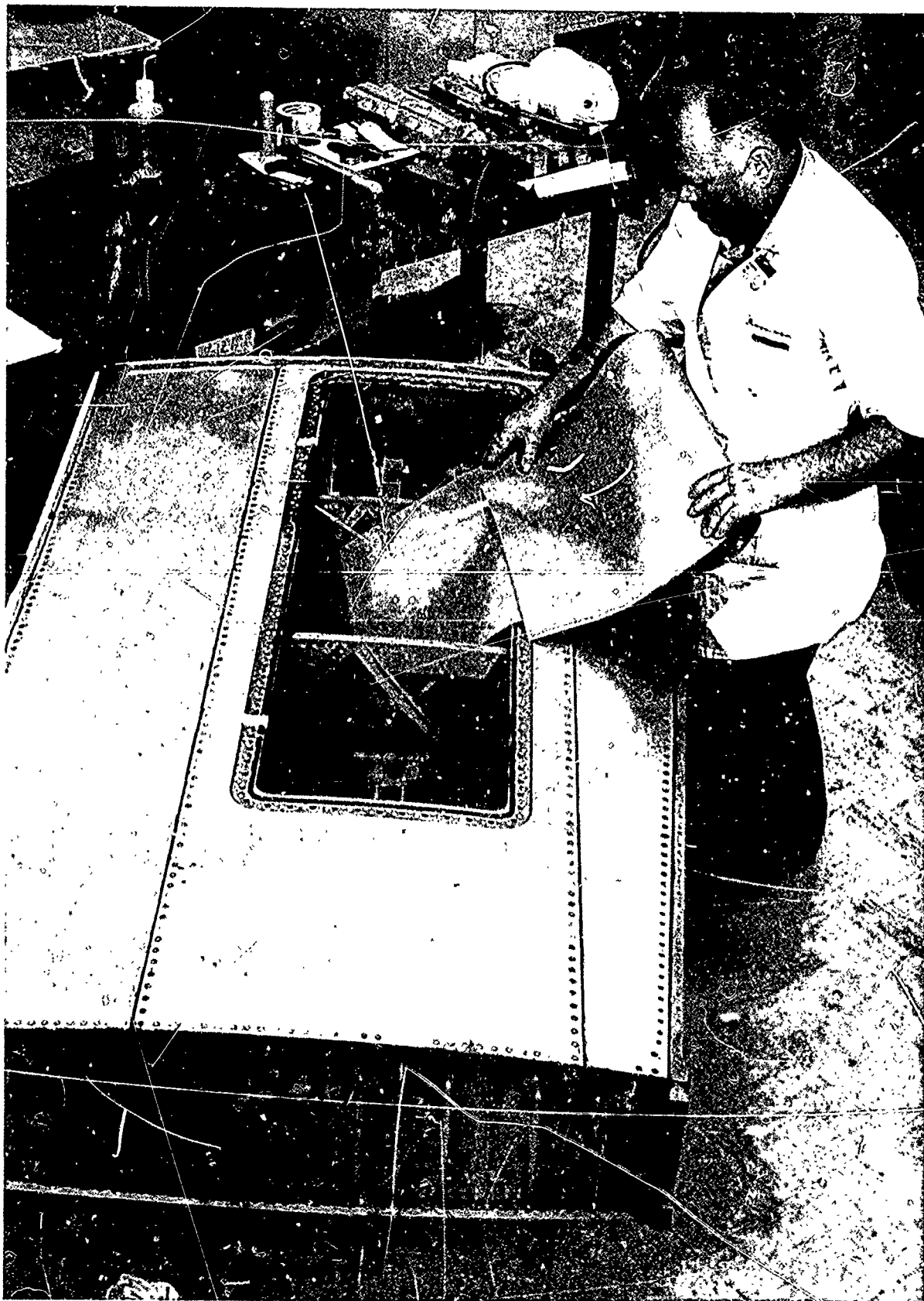


FIGURE 33. INSTALLATION OF A PLAIN LAMINATE IN A TANK BAY



FIGURE 34. SLOSH AND VIBRATION TEST TANK WITH DAMAGE CONTROL
AND SELF-SEALING SYSTEMS INSTALLED

to 7/8 inch. This was necessary because the rib height in the Outer Wing Stations (OWS) of the firing test tank measures approximately 7/8 inch. The raising of the ribs of the mold from 5/8 inch to 7/8 inch was accomplished with metal filler strips. The resulting corrugated laminates were of good quality and fitted each bay perfectly.

The corrugated laminates for the asymmetrical corner-sections of the firing test tank were fabricated using the special molds, as described in C.2. above. The procedure of fabrication was again similar to the one described in C.1. above.

For the installation of the corrugated laminates in the symmetrical and asymmetrical bays in the bottom sections of the firing test tank, the procedure in C.3. above was used. Corrugated laminates were installed in all of the seven bays situated between OWS 283 and OWS 403. The bay OWS 403 to OWS 421 was left bare.

The precompressed foam and the plain flat flexible laminates were installed in the firing test tank in the same way as they were in the slosh and vibration test tank (see Sections C.4. and C.6. above). The installation was performed in only the six bays which are situated between OWS 300 through OWS 403. The bay between OWS 283 and OWS 300 had only the corrugated laminate (damage control system) installed in it. Figure 35 shows the corrugated laminate installed in OWS 283 to OWS 300, and the completed self-sealing system installed in OWS 300 through OWS 334. Figure 36 shows the complete self-sealing system installed in the bays situated between OWS 351 through OWS 403. The weight of the system installed was 1.85 pounds/foot². The thickness of the system exceeded the height of the structural ribs (7/8-inch) by 3/16 of an inch.

To protect the top sections of the firing test tank against the exiting projectiles during the firing tests, corrugated laminates were installed against these top sections in the bays situated between OWS 300 through OWS 403. Because the rib height (1 1/8 inch) and the rib spacing (1 1/2 inch) were different from the rib height (7/8 inch) and rib spacing (1 3/4 inch) of the bottom sections of the tank, a completely different mold had to be used for the fabrication of the corrugated laminates. This mold (1 1/2 feet X 5 feet) was obtained by dismantling the top C-130 skin structure of the wing station OWS 248 to OWS 265. Once the mold was prepared, the fabrication of the corrugated laminates (six of them) and the installation at the top sections of the tank were performed in a similar fashion to the fabrication and installation of the corrugated laminates at the bottom sections of the slosh and vibration and firing test tanks. Among the six corrugated laminates fabricated, some were four-ply, some five-ply, and some seven-ply. The four-ply laminates used the 14 oz. ballistic nylon cloth and the five-ply and seven-ply laminates used the 9 oz. ballistic nylon cloth.

E. SLOSH AND VIBRATION TESTS

Tests were conducted to evaluate the ability of the self-sealing and damage protection system, as installed in the C-130 wing fuel tank, to withstand slosh and vibration testing. The tank section used was from OWS 491 to OWS 562, with the self-sealing and damage control systems installed in the three bays between OWS 491 and OWS 544.

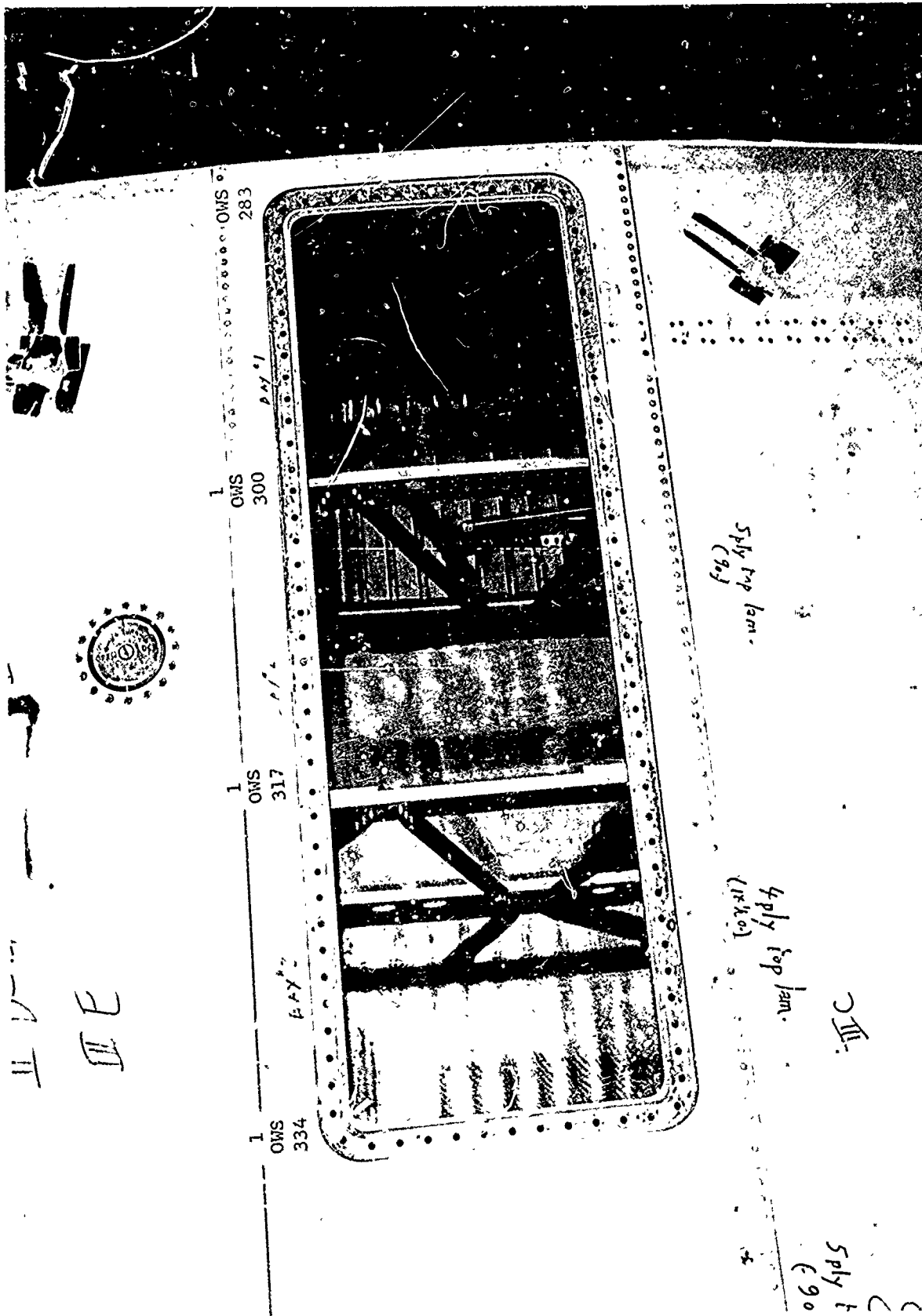


FIGURE 35. CORRUGATE LAMINATE IS INSTALLED IN OWS 283 TO OWS 300 AND SELF-SEALING SYSTEM IS INSTALLED IN OWS 300 THROUGH OWS 334 OF THE FIRING TEST TANK

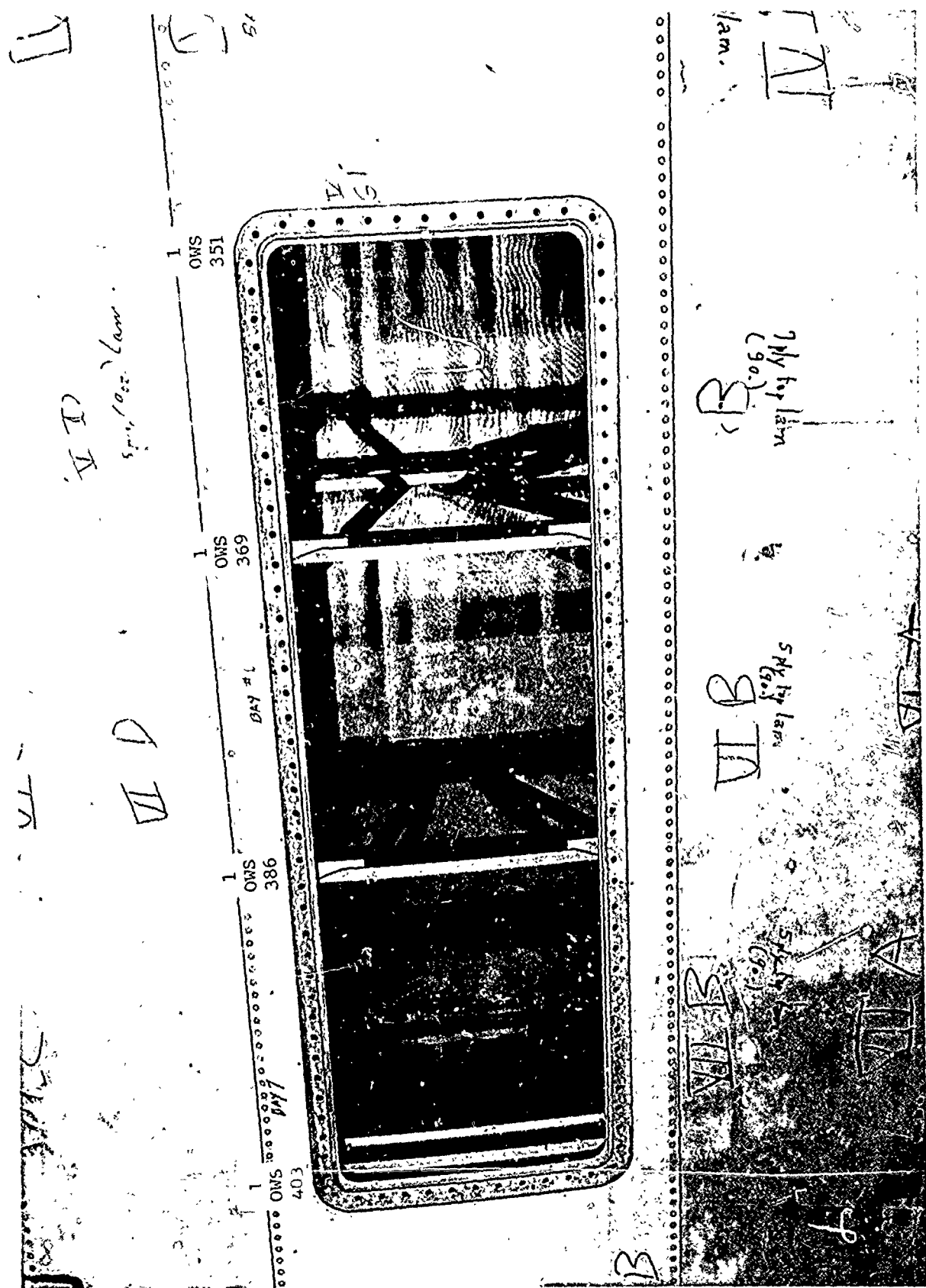


FIGURE 36. SELF-SEALING SYSTEM INSTALLED IN OWS 351 THROUGH OWS 403 OF THE FIRING TEST TANK

The tank was mounted (Figure 37) to the slosh and vibration table by means of a cradle assembly and straps. The tank was filled two-thirds full of JP-4 fuel (approximately 115 gallons).

The slosh and vibration tests were conducted per the requirements of MIL-T-6396C. The .032 double amplitude (D.A.) vibration called for in the Mil. Spec. was measured (Figure 38) along the bottom skin line immediately adjacent to the cradle supports. Six readings were taken and the vibration weights adjusted to give an average of the six readings at .032 D. A. The readings were taken at the forward, center, and aft locations along each support. The vibration was applied at 1950 rpm. The slosh angle was adjusted to be ± 15 degrees giving a slosh rate of 16 cycles per minute.

After 5 1/2 hours of testing per the above procedure, a loud "pop" type sound was heard from inside the tank. Investigation revealed that at least two vertical trusses had failed on the Stations 509 and 526 rib structures. A resultant radical change in vibration levels at the measurement points listed above was also noted. The test was shut down at this point in order to consult with ASD regarding their recommendations for further testing.

Consultation with AFML Program Project Monitor produced a mutual decision to continue tests with slosh only. No repairs were made on the failed trusses. The sloshing was continued until a total test time of 25 hours had been reached.

Inspection of the tank following conclusion of the testing and drainage of the JP-4 fuel revealed the following:

1. No evidence of delamination or tearing of the damage protection and self-sealing systems (Figure 39).
2. Two failed vertical trusses in the Stations 509 and 526 rib structures.

F. FIRING TESTS AT CHINA LAKE TEST FACILITY

After the installation of the self-sealing system and the damage control system in the bottom and top sections of the firing test tank, the reticulated foam (orange type) was cut (Figure 40) to fit and installed inside the tank as shown in Figure 41. The two covers were then bolted on top of the tank. The outside bottom part of the tank was spray-painted white and marked as shown in Figure 42.

To mount the tank on the firing test platform at China Lake, the tank was framed in a 10-inch steel channel and strapped on both sides by 3/16-inch X 2-inch cold rolled steel bands as shown in Figure 42. Neoprene rubber padding was used between the tank surfaces and the straps. It was at this stage that the tank was sent to the China Lake Test Facility (Figure 43). With the help of mounting brackets welded to the metal frame, the tank was attached to the three extension legs as shown in Figure 44. The tank was also slightly tilted to allow near vertical shots with the .50 caliber gun.



FIGURE 37. SLOSH AND VIBRATION TESTS

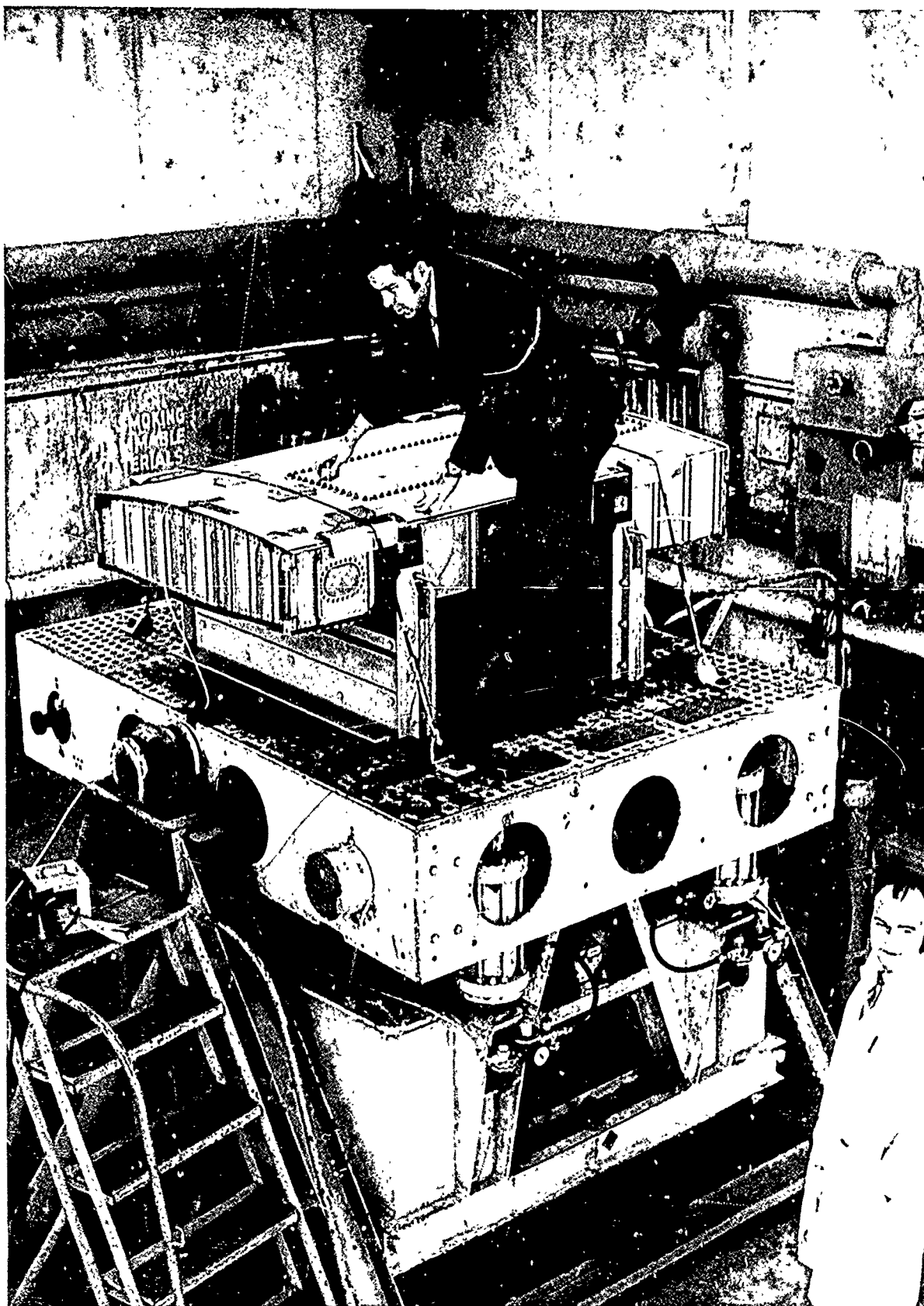


FIGURE 38. MEASUREMENT OF THE VIBRATION AMPLITUDE



FIGURE 39. INSPECTION OF TANK AFTER SLOSH AND VIBRATION TESTS



FIGURE 40. CUTTING OF RETICULATED FOAM

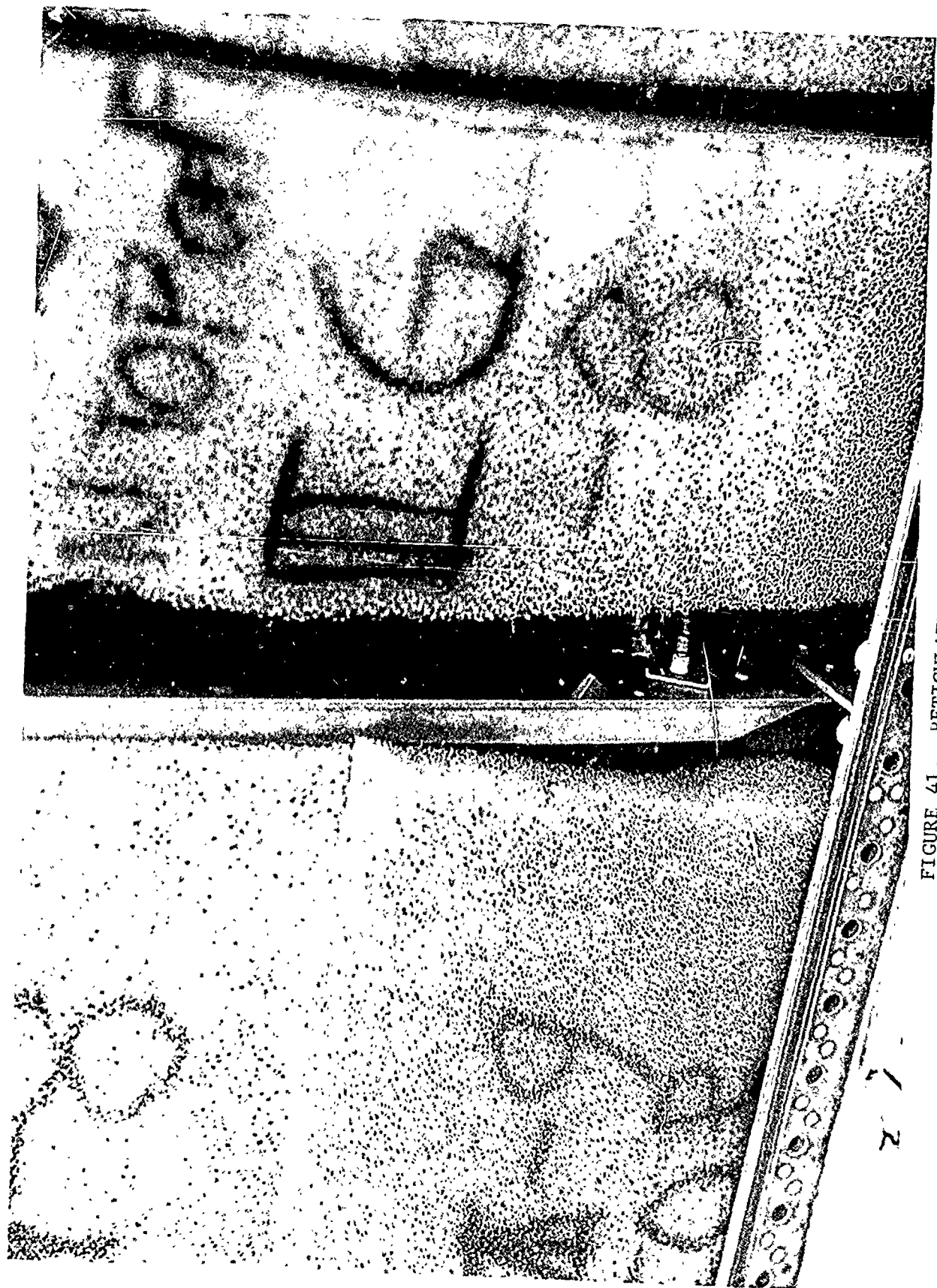


FIGURE 41. RETICULATED FOAM INSTALLED

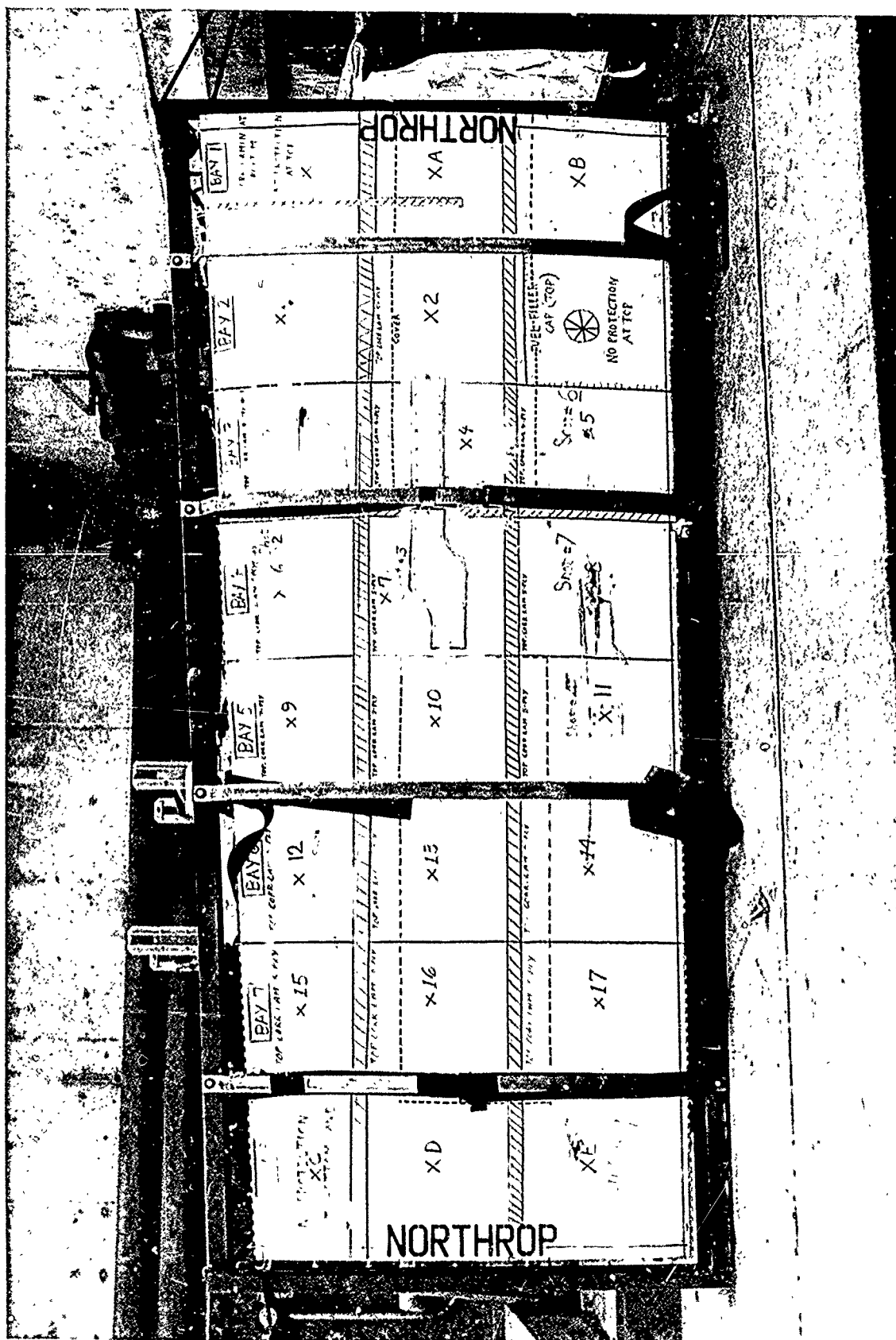


FIGURE 42. FIRING TEST TANK WITH MARKINGS

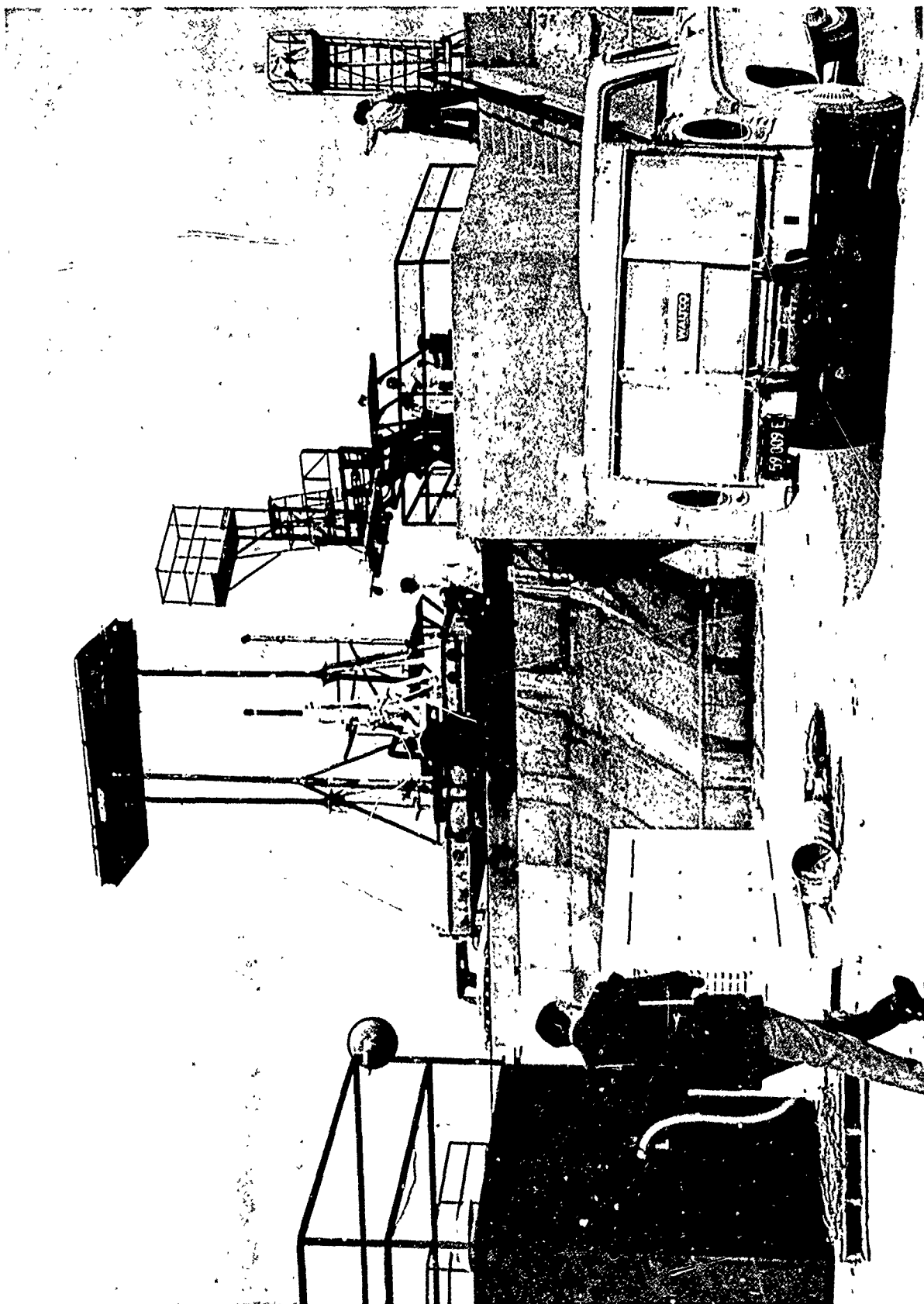


FIGURE 43. CHINA LAKE TEST FACILITY

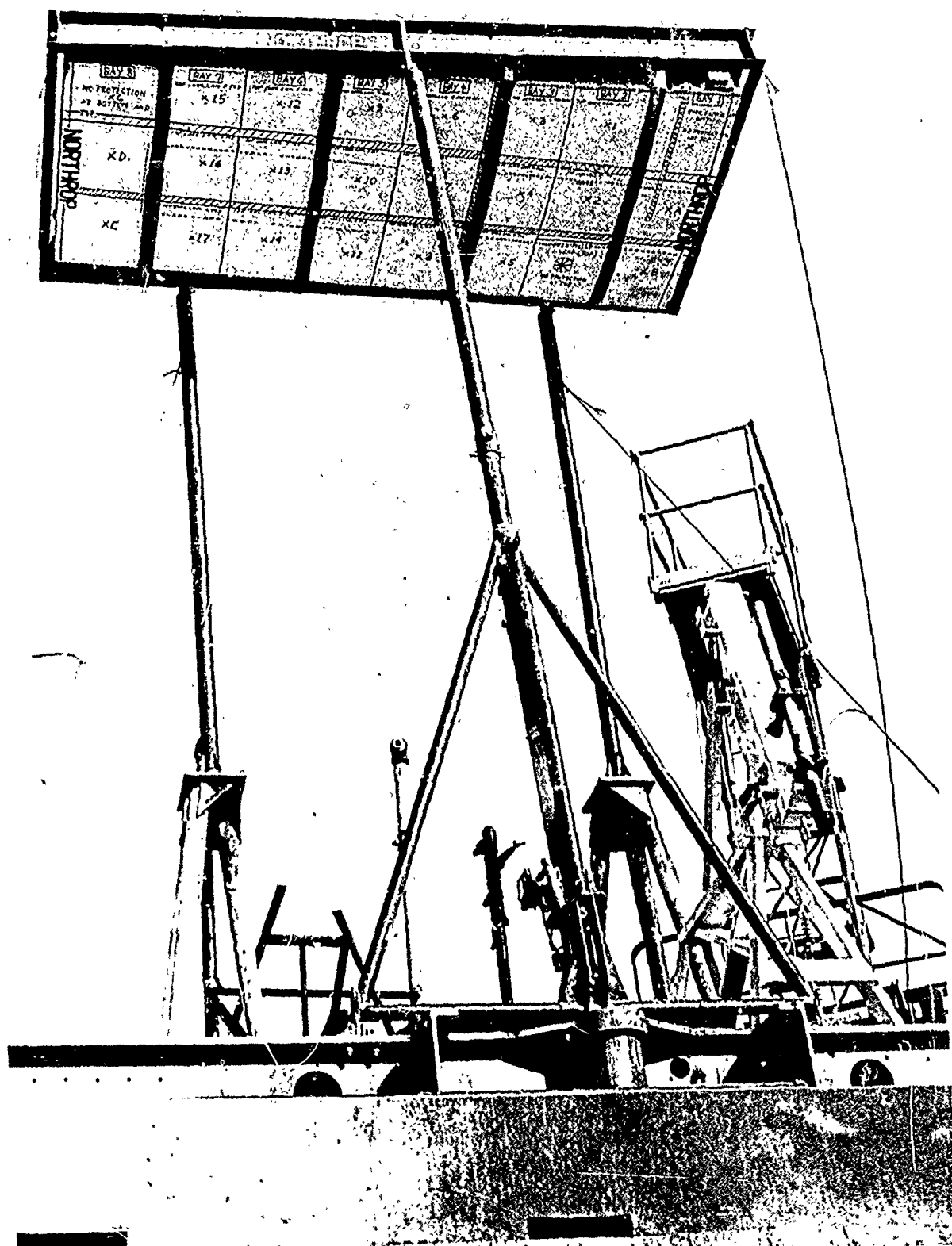


FIGURE 44. FIRING TEST TANK MOUNTED ON THE TEST STAND

Finally, the tank was filled 2/3 full with JP-5 fuel.

Actual Tests

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
1	.50 caliber AP	Vertical	Bay 6, X 12

Results

The projectile hit straight on, not tumbled, at the entry. On its way in, it hit a rib. The damage provoked at the entry was a 1/2-inch diameter circular hole. The precompressed foam partially sealed the hole as shown in Figure 45. The plain laminate bonded to the precompressed foam behind the entry wall of the tank showed a tiny hole as illustrated in Figure 46. The initial leakage through the entry hole was approximately 60 cc/min., which dropped two hours later to almost 0 cc. The leakage was measured by means of a long plastic pipe, which was adapted at one end against the punctured hole. The leaking fuel was then collected in a graduated cylinder and measured.

The projectile exited the tank in a fully tumbled condition as Figure 47 shows. A 3-inch X 3-inch piece of metal skin was removed. The butt and tip of the projectile each hit a rib and ruptured them. The corrugated laminate (five-ply) shows a 2-inch long slit. While traveling through the tank, the projectile did not hit other segments of the tank structure. In a scaled sketch of the tank (Figure 48), the points of entry and exit and the path of the projectile through the tank are given.

Due to technical difficulties, the high-speed cameras failed to work and no films were obtained in this test.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
2	.50 caliber AP	45° from vertical (aft to forward)	Bay 4, X 6

Results

In this shot, the projectile penetrated the tank entry wall in a 45° angle of incidence and hit a rib. The rib ruptured but the precompressed foam, the corrugated laminate, and the plain laminate, kept the damage low. The damage at the entry was a 1/2-inch diameter hole slightly deformed due to the 45° angle impact, as seen in Figure 49. The plain laminate showed a small hole as illustrated in Figure 50. The heavy damage seen on this last picture was due to shot No. 8 (20 mm.), and not to shot No. 2. Measurement of the leakage using the plastic pipe indicated a rate of approximately 30 cc./min. After awhile, this small leakage had appeared to have dropped considerably below this figure.

As Figure 51 shows, the projectile hit the exit wall in a fully tumbled

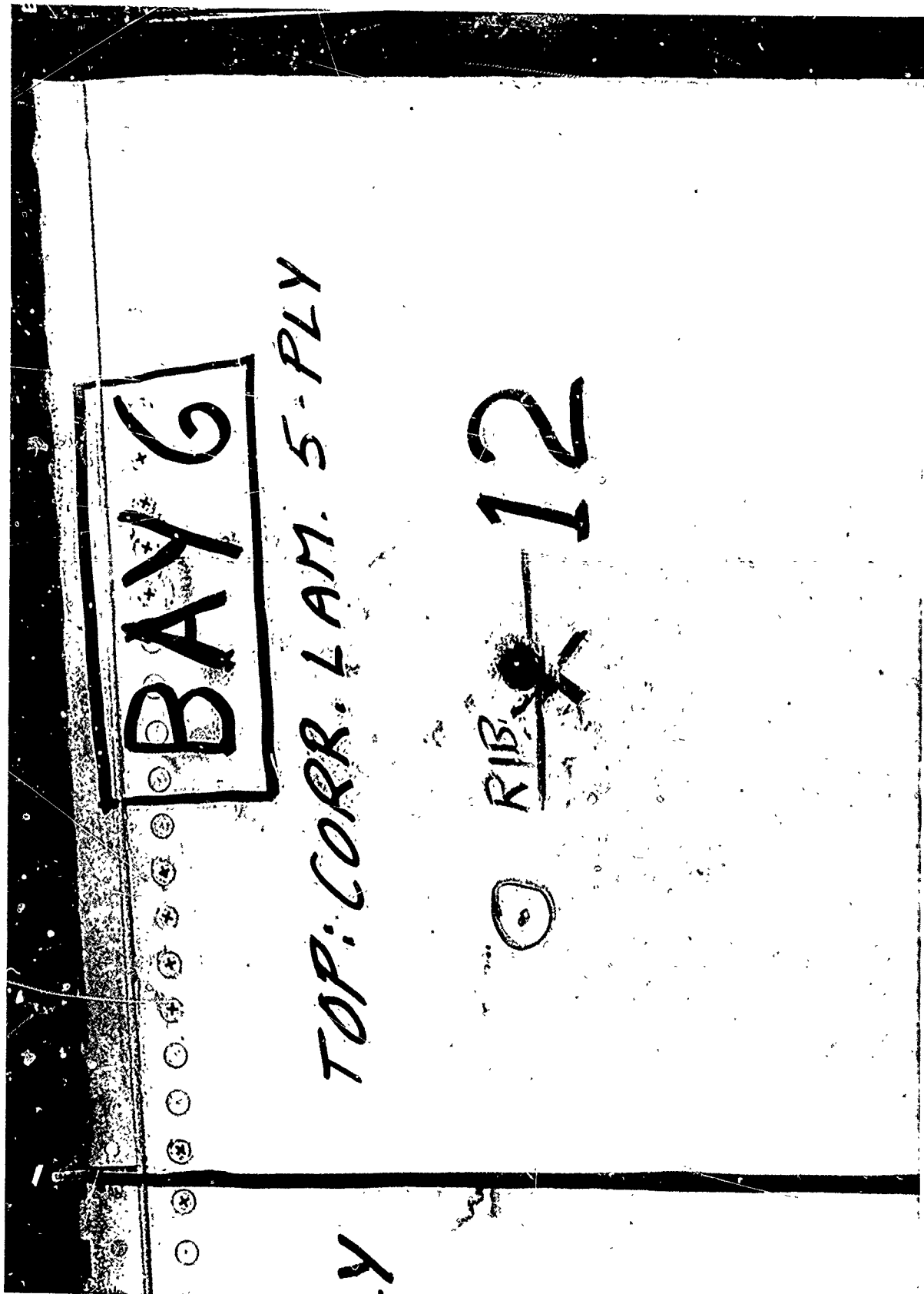


FIGURE 45. TEST NO. 1, .50 CALIBER AP VERTICAL - ENTRY FACE OF THE TANK

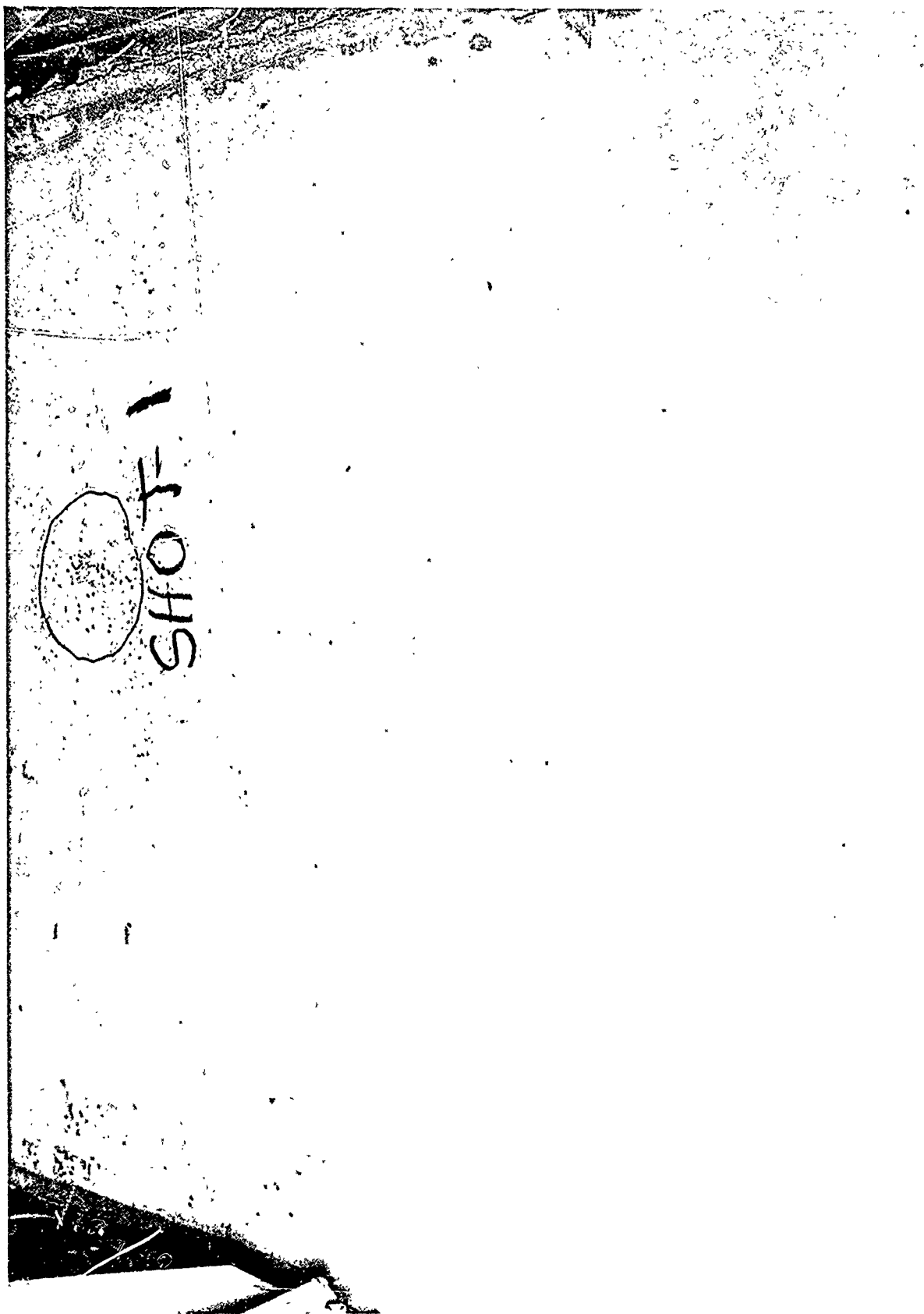


FIGURE 46. TEST NO. 1, .50 CALIBER AP VERTICALLY, - PLAIN LAMINATE BEHIND THE ENTRY WALL



FIGURE 47. TEST NO. 1, .50 CALIBER AP VERTICAL - EXIT FACE OF THE TANK

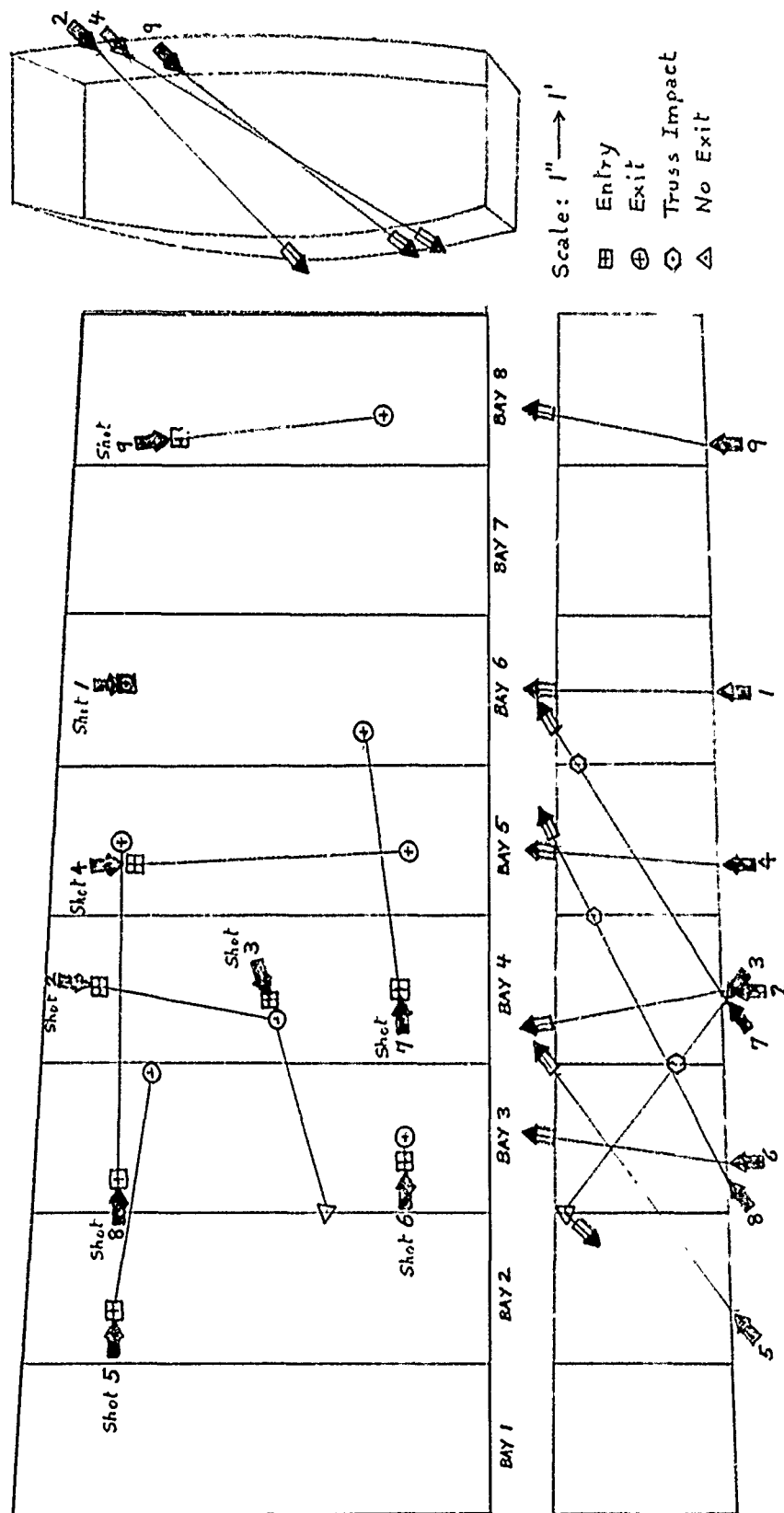


FIGURE 48. SKETCHES SHOWING TANK IMPACT POINTS AND TRAJECTORY OF PROJECTILE FOR ALL NINE SHOTS

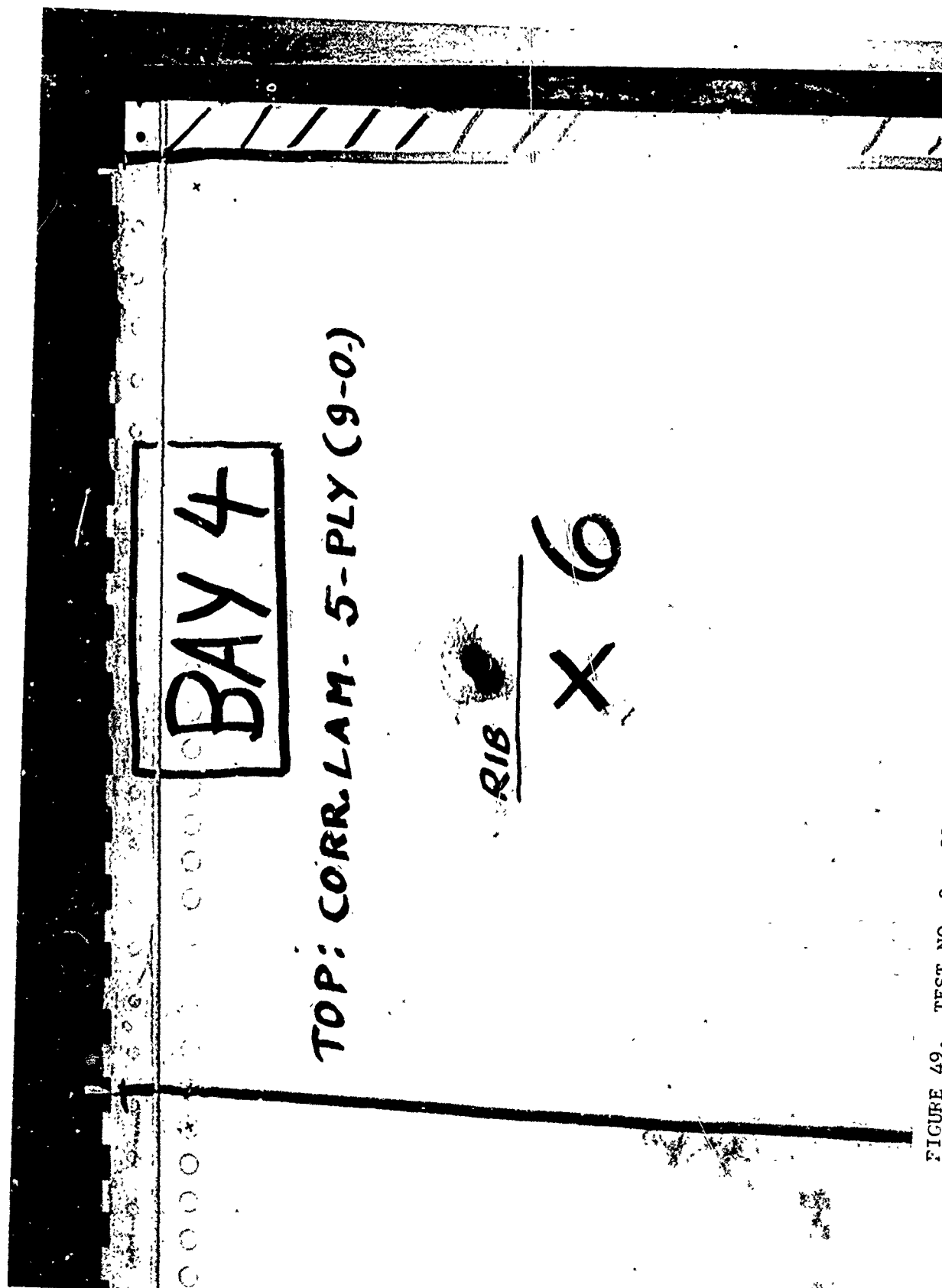


FIGURE 49. TEST NO. 2, .50 CALIBER AP, 45° FROM VERTICAL - ENTRY FACE OF THE TANK

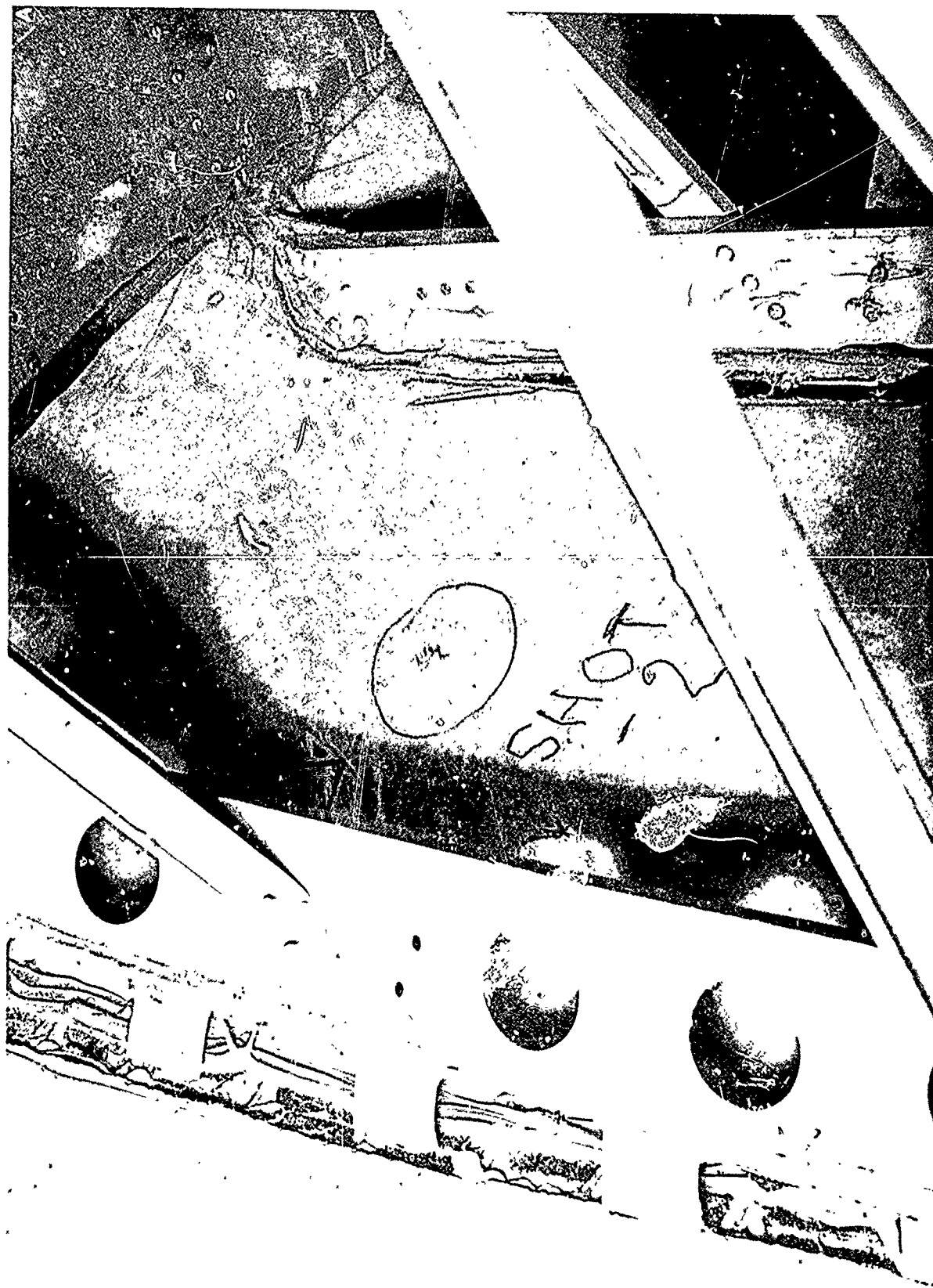
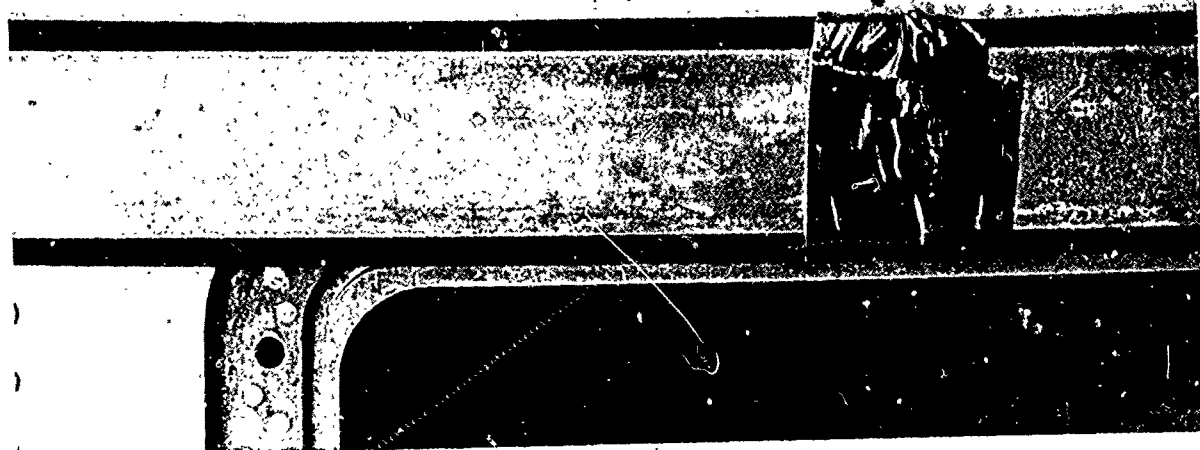


FIGURE 50. TEST NO. 2, .50 CALIBER AP 45° FROM VERTICAL - PLAIN LAMINATE
BEHIND THE ENTRY WALL IS SHOWN



SHOT-2
EXIT

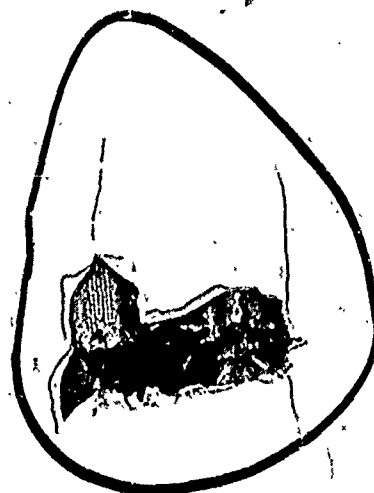


FIGURE 51. TEST NO. 2, .50 CALIBER AP, 45° FROM VERTICAL - EXIT FACE OF THE TANK

condition and removed a 2 1/2-inch X 1-inch piece of metal skin. The corrugated laminate (five-ply) on the exit wall was torn slightly in the vicinity of the puncture. The butt and tip of the tumbling projectile hit two ribs which ruptured, but the damage was contained by the corrugated laminate. No vertical trusses or other parts inside the tank were hit by the projectile as it traveled through the tank. The sketch in Figure 48 gives the points of entry and exit on the tank and the trajectory of the projectile through the tank. In this shot, the high-speed cameras worked and high-speed motion pictures were obtained.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
3	.50 caliber AP	45° from vertical (outboard to inboard)	Bay 4, X 7

Results

The projectile penetrated in a 45° angle of incidence and hit a rib longitudinally as shown in Figure 52. The projectile tumbled immediately behind the entry metal skin and exited the plain laminate or the entry skin in a fully tumbled condition. This was ripped as is shown in Figure 53. This sudden tumbling of the projectile right behind the entry wall and the rupturing of the rib dumped a tremendous amount of energy at this spot and produced a high pressure ram wave. This provoked a long crack (approximately 39 inches) and some petalling at the metal skin entry wall, as is shown in Figure 52. The leakage recorded was 3.2 liters/min. After the entry, the tumbling projectile proceeded through the tank. Before it was stopped inside the tank, it fractured two vertical trusses (OWS 334 and OWS 317) and hit part of the cover. The hit cover and one of the hit trusses are shown in Figure 54. The projectile was recovered in the reticulated foam next to that fractured truss. On the sketch in Figure 48, the points of impact of the projectile and its trajectory through the tank are shown. Coverage with the high-speed motion picture cameras was obtained of this shot.

The distorted truss shown in Figure 53 was caused by the 20 mm. AP impact and not by this No. 3 shot. The 20 mm. shot is described below.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
4	.50 caliber AP	45° from vertical (forward to aft)	Bay 5, X 11

Results

At entry, the projectile hit a rib laterally and ruptured it. Some deformation occurred at the entry hole due to the 45° angle impact (see Figure 55). The plain laminate behind the entry wall showed minor damage as is illustrated in Figure 56. The leakage measured was approximately 130 cc/min. This leakage reduced to about 70 cc/min. about 45 minutes after the shot. At the exit side of the tank, the projectile hit the metal skin in a slightly tumbled position, ruptured one rib, and bent another. The corrugated

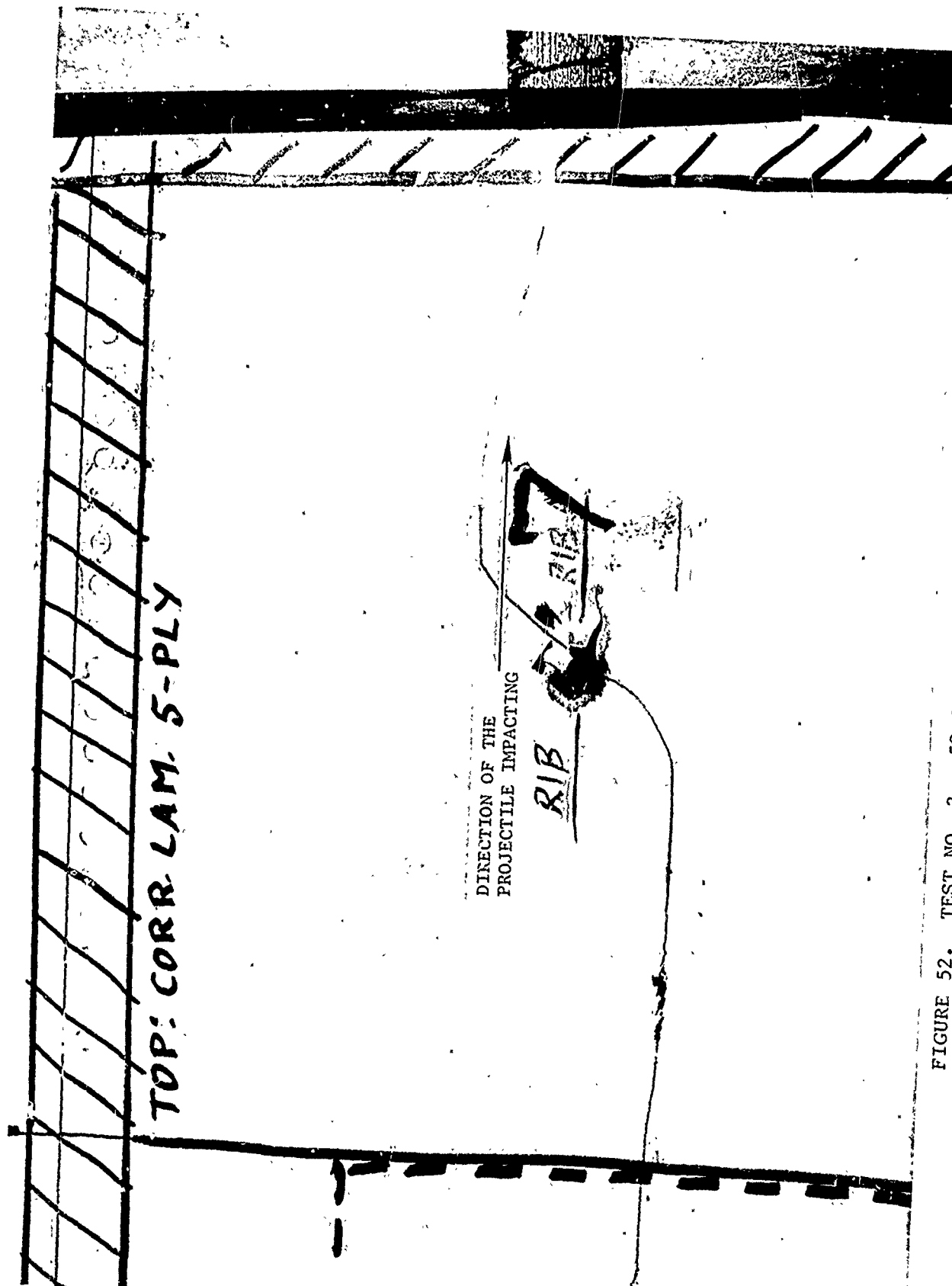


FIGURE 52. TEST NO. 3, .50 CALIBER AP, 45° FROM VERTICAL -
ENTRY FACE OF THE TANK



FIGURE 53. TEST NO. 3, .50 CALIBER AP, 45° FROM VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL IS SHOWN



FIGURE 54. TEST NO. 3, .50 CALIBER AP, 45° FROM VERTICAL -
IMPACT OF PROJECTILE NEAR EXIT FACE OF TANK

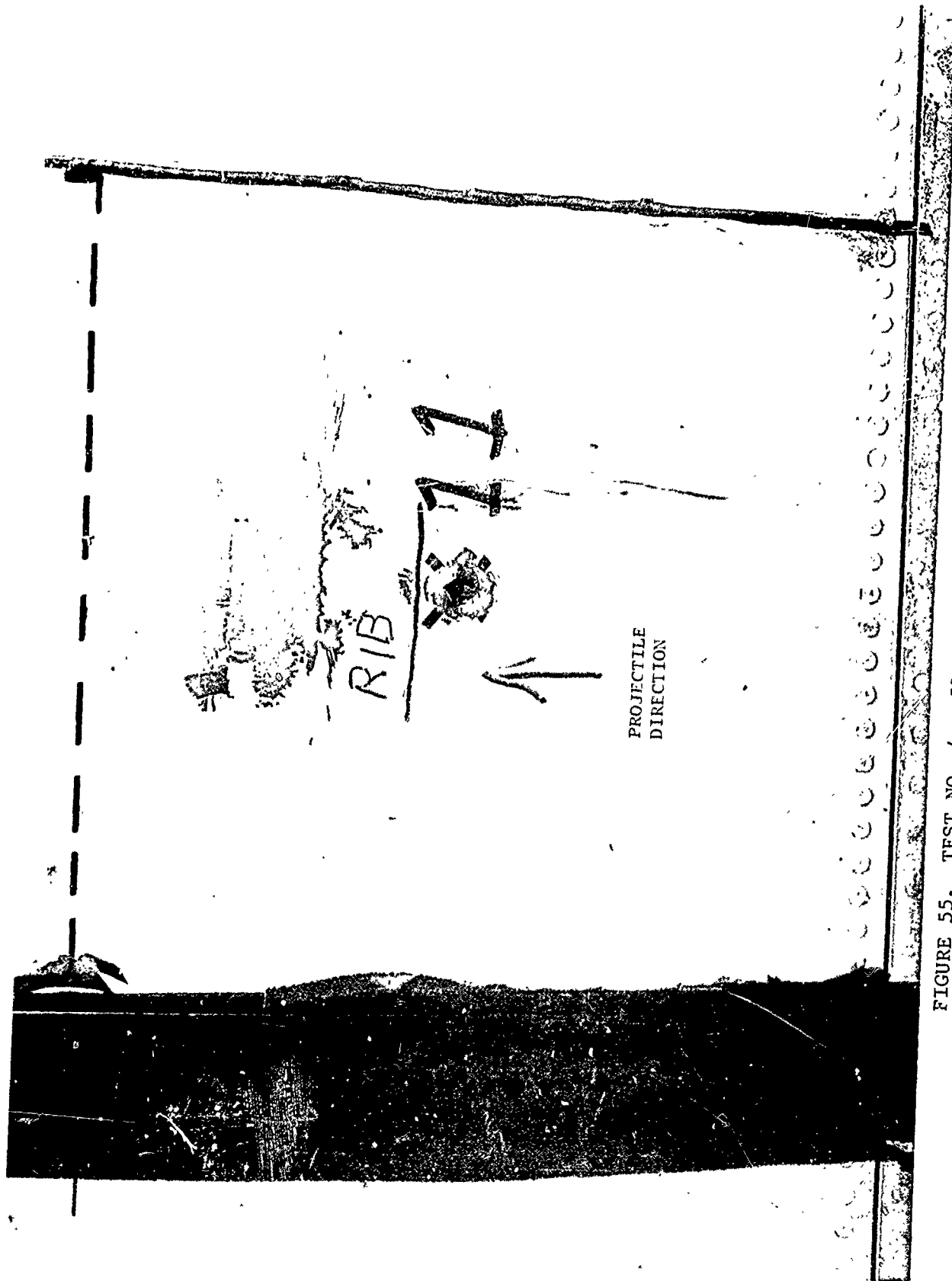


FIGURE 55. TEST NO. 4, .50 CALIBER AP, 45° FROM VERTICAL -
ENTRY FACE OF THE TANK



FIGURE 56. TEST NO. 4, .50 CALIBER AP, 45° FROM VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL

laminate (seven-ply) bonded against the skin showed a 1-inch long slit and the metal skin suffered a 1-inch X 3/4-inch hole which was contained by the corrugated laminate (see Figure 57). The points of impact and the trajectory of the projectile through the tank are shown on sketch in Figure 48. High-speed motion pictures of the shot were obtained.

After shot No. 4, the tank was defueled and taken to the repair area. The entry holes and the cracks of the first four shots were patched using rubber gaskets, metal plates, rivets, and 898 polysulfide sealant. The next day, the firing tests were continued.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
5	.50 caliber AP	45° from vertical (inboard to outboard)	Bay 2, X 1

Results

As shown in Figure 58, the entry metal skin suffered only minor damage. The 1/2-inch diameter hole was slightly deformed due to the 45° angle impact. The picture also shows the precompressed foam behind the metal skin sealing the punctured hole. A rib was hit and bent in this test. The damage to the plain laminate behind the entry wall was also minor (see Figure 59). The leakage was very small, only 25 cc./min. were measured. This rate of leakage was reduced to 0 after approximately one hour.

After penetrating the entry wall of the tank, the projectile proceeded to the exit wall without hitting a vertical truss. At the exit, it hit in a fully tumbled condition in the area of OWS 334, removing a 3-inch X 1 1/2-inch metal piece, partially hitting the metal strap, and leaving a 1 1/2-inch long slit in the corrugated four-ply laminate, which reduced the hole size (see Figure 60). The projectile did not hit a rib at the exit. For a better view of the projectile trajectory and its points of impact in this particular shot, see Figure 48. All the high-speed cameras ran smoothly and high-speed motion pictures were obtained.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
6	.50 caliber API	Vertical	Bay 3, X 5

This shot was the first of the two .50 caliber API impacts performed during this series of tests. As can be seen in Figure 61, the damage at the entry metal skin was a clean 1/2-inch diameter hole which was practically sealed immediately on impact by the precompressed foam and the flexible laminates behind the skin. The leakage was 20 drops/min. and reduced to 0 after one hour. This was the only shot where the projectile did not hit a rib on entry. The plain laminate behind the entry wall showed a small hole (see Figure 62). This laminate did most of the sealing. On its way to the exit wall of the tank, the projectile did not hit any other parts of the tank. At the exit, the projectile hit in a partially tumbled condition.

REPORT

Shot 2 ~~#~~

SHOULD BE SHOT NO. 4



x6

7 ply for film
(90.)

R

FIGURE 57. TEST NO. 4, .50 CALIBER AP, 45° FROM VERTICAL -
EXIT FACE OF THE TANK

BAY 2

FOR CUTTING - 5-PLY

Shot # 5

X 1

50 CAL AP

45°

PROJECTILE
DIRECTION

FIGURE 58. TEST NO. 5, .50 CALIBER AP, 45° FROM VERTICAL -
ENTRY FACE OF THE TANK

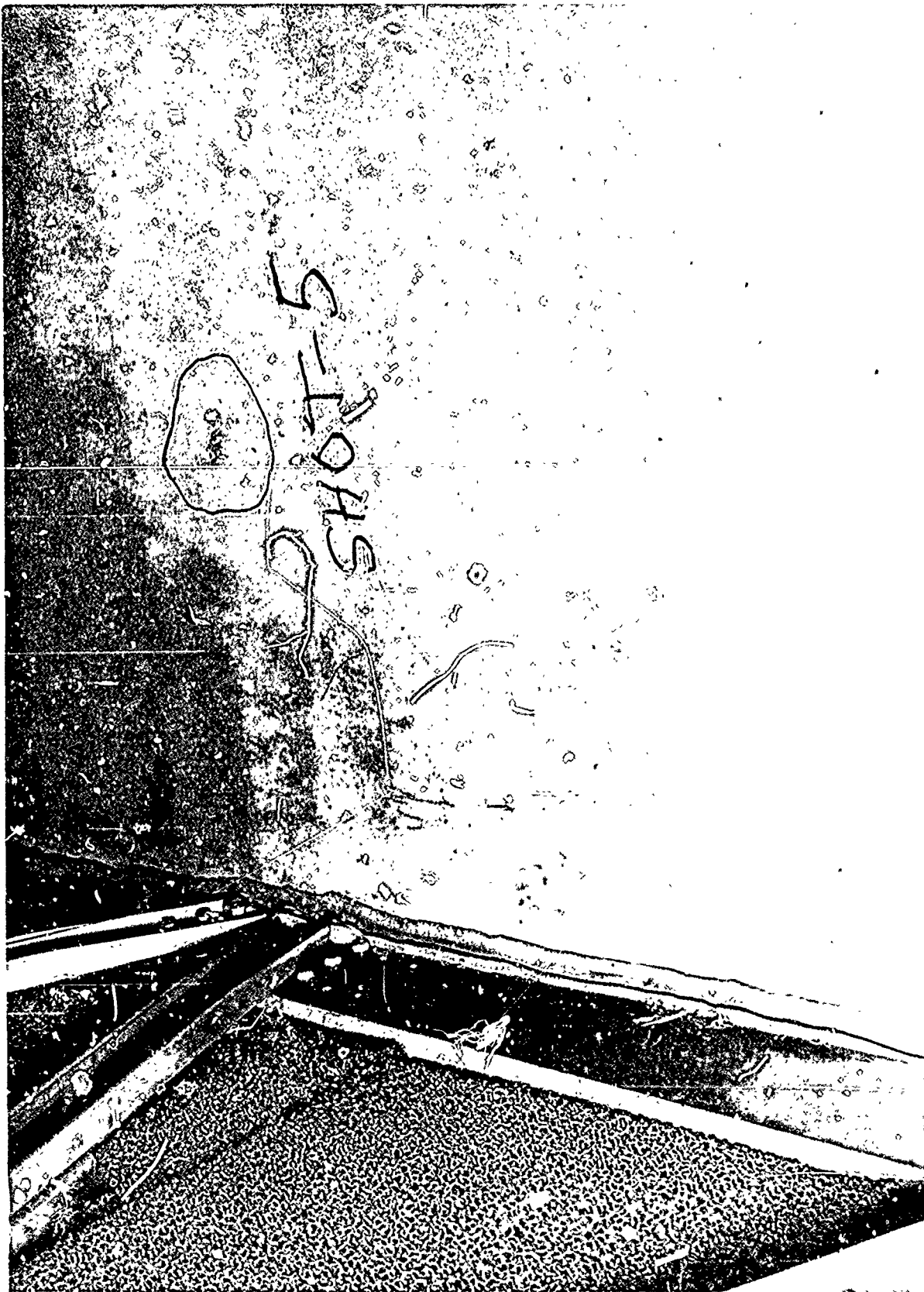


FIGURE 59. TEST NO. 5, .50 CALIBER AP, 45° FROM VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL

1
 2
 3
 4

LOUIS

4 ply top lam.

(1840)

52

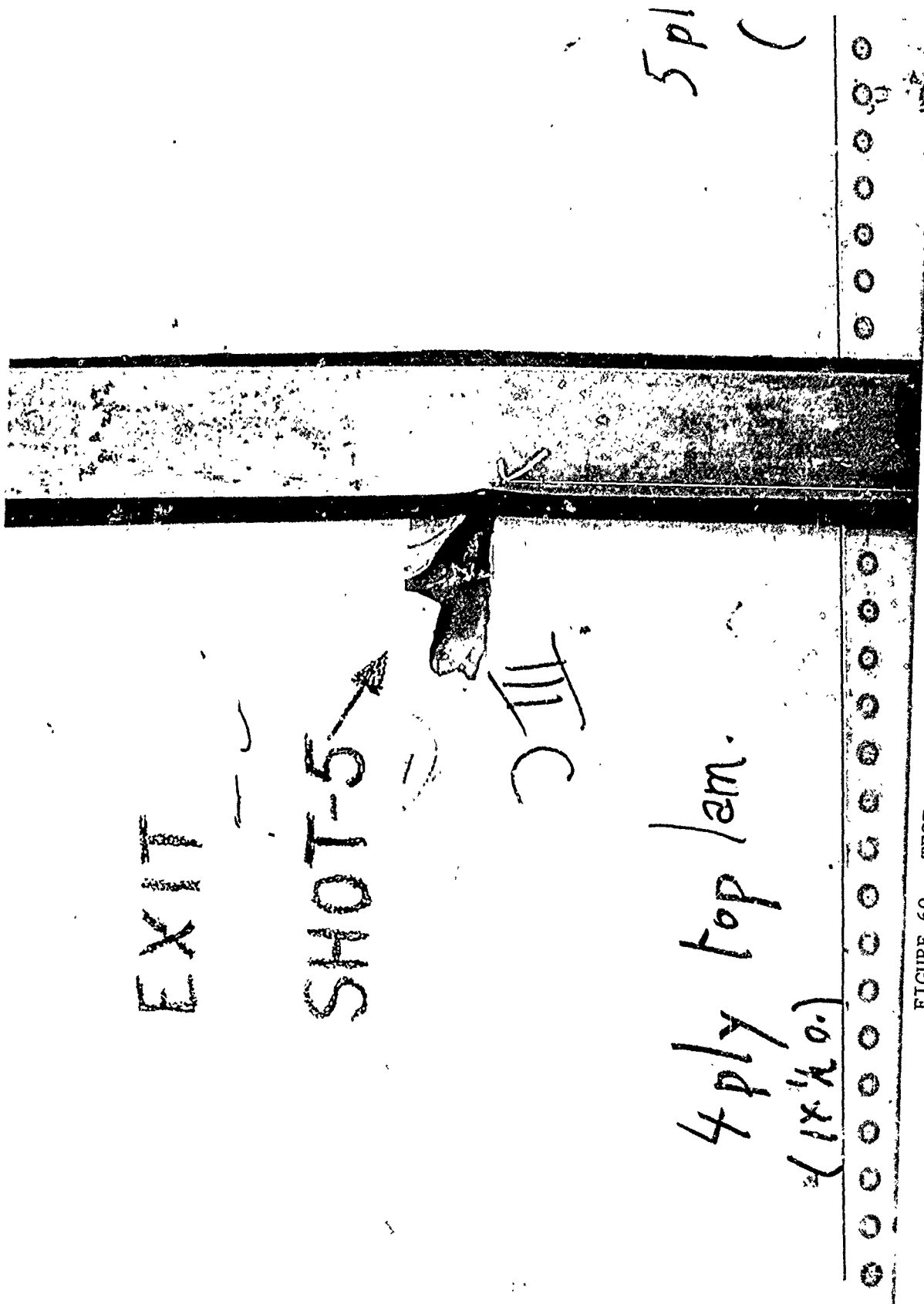


FIGURE 60. TEST NO. 5, .50 CALIBER AP, 45° FROM VERTICAL -
EXIT FACE OF THE TANK

TOP; CORR-LAN. 4-PLY

Shot # 6
50 CAL
API
VERT

NO

FIGURE 61. TEST NO. 6, .50 CALIBER API, VERTICAL -
ENTRY FACE OF THE TANK



FIGURE 62. TEST NO. 6, .50 CALIBER API, VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL

This is evident in Figure 63; the four-ply laminate behind the metal skin showed a 1 1/4-inch long slit. A 2-inch X 1/2-inch metal piece the size of the .50 caliber projectile was removed from the skin structure. No ribs were hit by the projectile. From the high-speed motion pictures taken and observations during the shot, it was established that functioning of the API projectile took place after the projectile had exited the tank. The points of entry and exit and the path of the projectile through the tank are given in Figure 48.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
7	.50 caliber API	45° from vertical (inboard to outboard)	Bay 4, X 8

Results

The projectile penetrated the tank in a 45° angle and hit a rib longitudinally. This made the API projectile function immediately behind the entry metal skin. This was evident on the high-speed motion pictures, from the burned area in the vicinity of the entry hole, and observations made during the test. The projectile tumbled immediately upon entry. This combination of the projectile hitting a rib and functioning and tumbling immediately behind the entry wall produced the high pressure ram waves which were responsible for the damage shown in Figure 64. A major crack, 47 inches long, and minor cracks in the vicinity of the impact hole, occurred as shown on the figure. The damage to the plain laminate behind the entry metal skin indicates the tumbling of the projectile and the cracked rib (Figure 65). The tear in the laminate measured 1 inch X 1/2 inch. The leakage was 3 liters/min.

On its way to the exit tank wall, the projectile hit a vertical truss approximately 4 inches before exiting. This is indicated in the sketch of Figure 48.

At the exit, the projectile brushed a rib and hit a row of rivets, which apparently ruptured the projectile, and only pieces of the projectile exited the tank as it is shown in Figure 66. The corrugated laminate bonded behind the exit wall skin kept the damage low.

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
8	20mm. AP	45° from Vertical (Inboard to Outboard)	Bay 3, X 3

Results

Similar to shot No. 7, the projectile penetrated the tank in a 45° angle of incidence and hit a rib longitudinally. This made the projectile tumble immediately behind the tank entry skin. This combination of events dumped a tremendous amount of energy in the form of high pressure waves right behind the entry wall. These pressure waves provoked large deformations of the tank

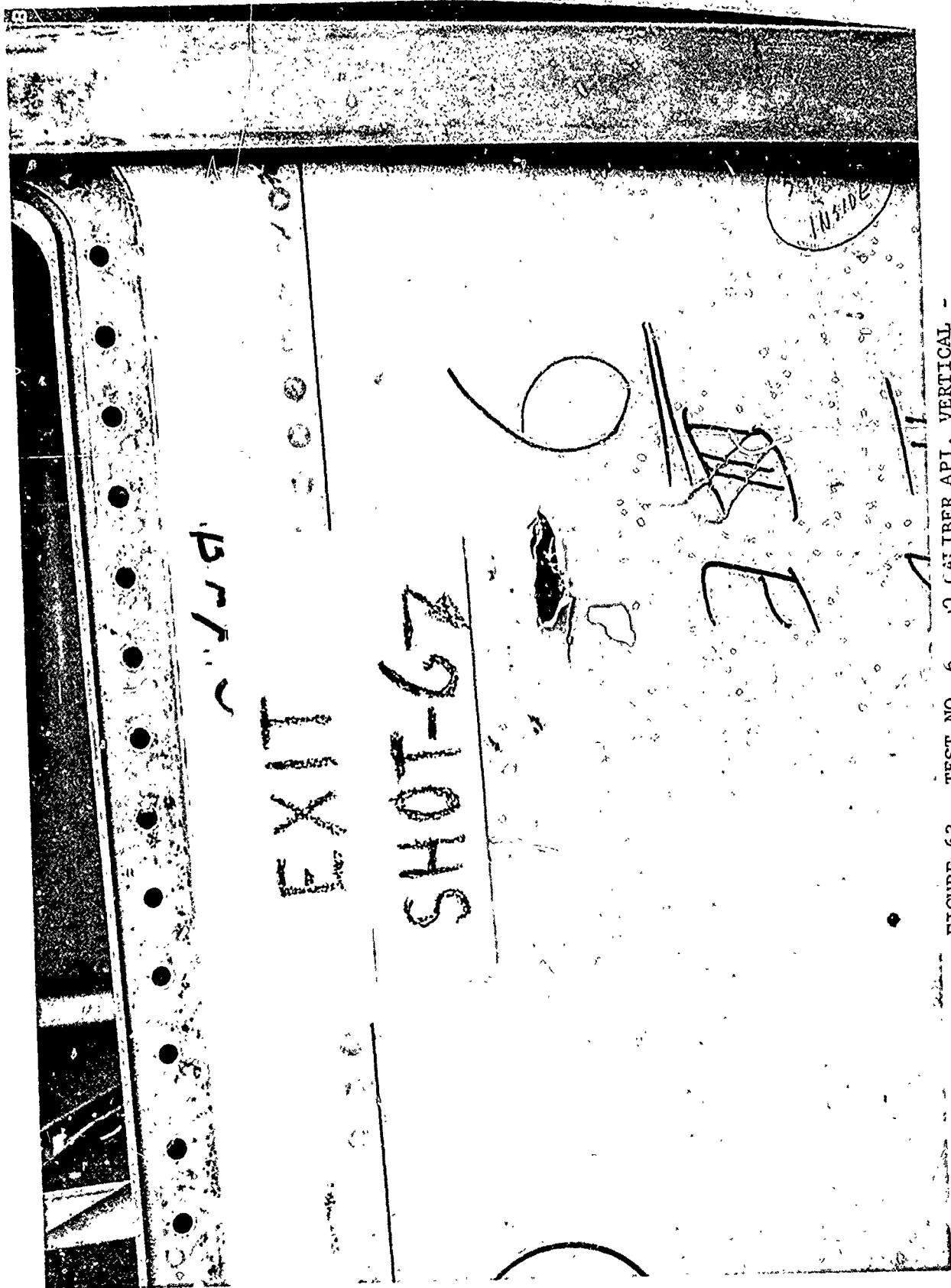


FIGURE 63. TEST NO. 6, .50 CALIBER API, VERTICAL -
EXIT FACE OF THE TANK

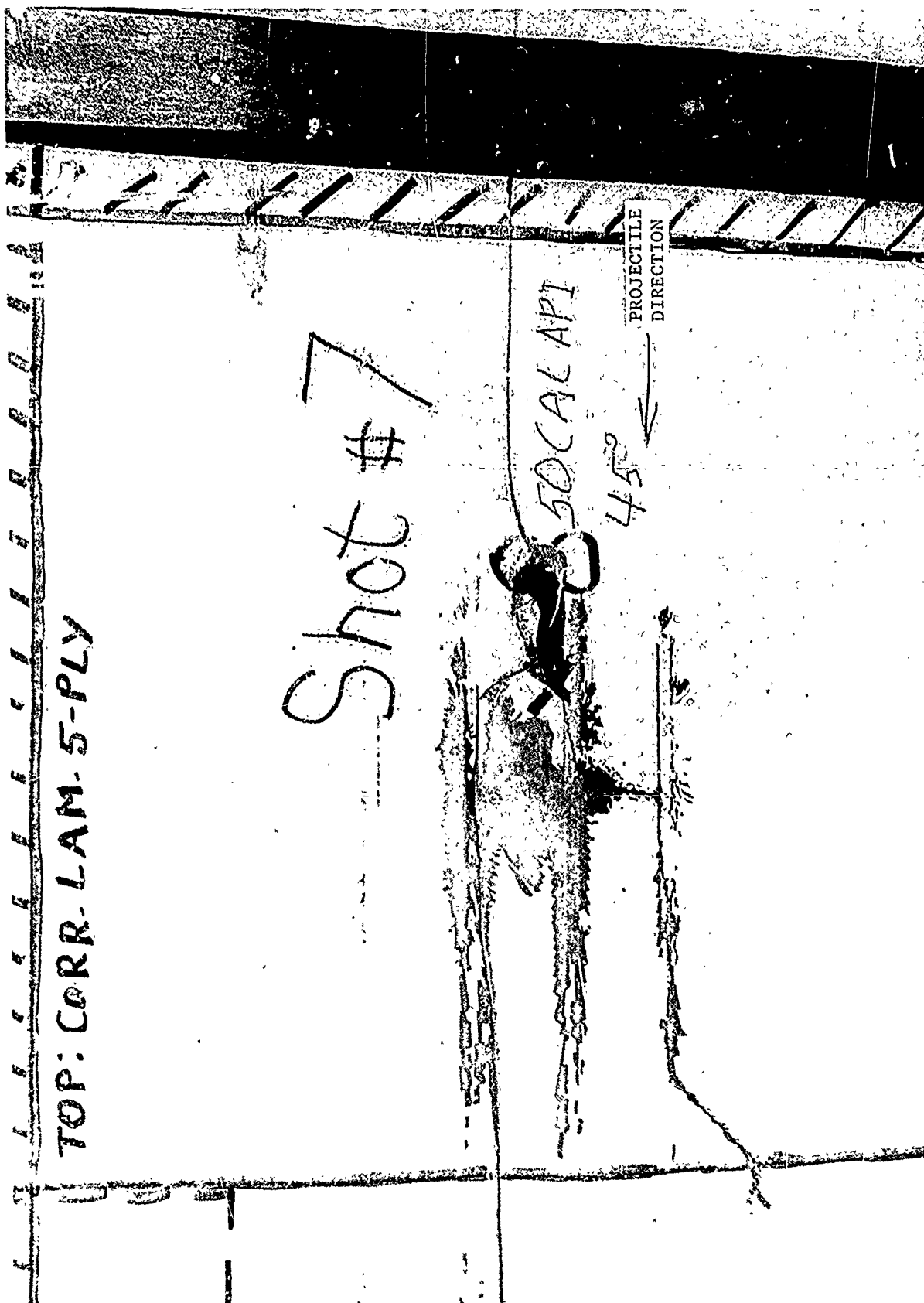


FIGURE 64. TEST NO. 7, .50 CALIBER API, 45° FROM VERTICAL -
ENTRY FACE OF THE TANK

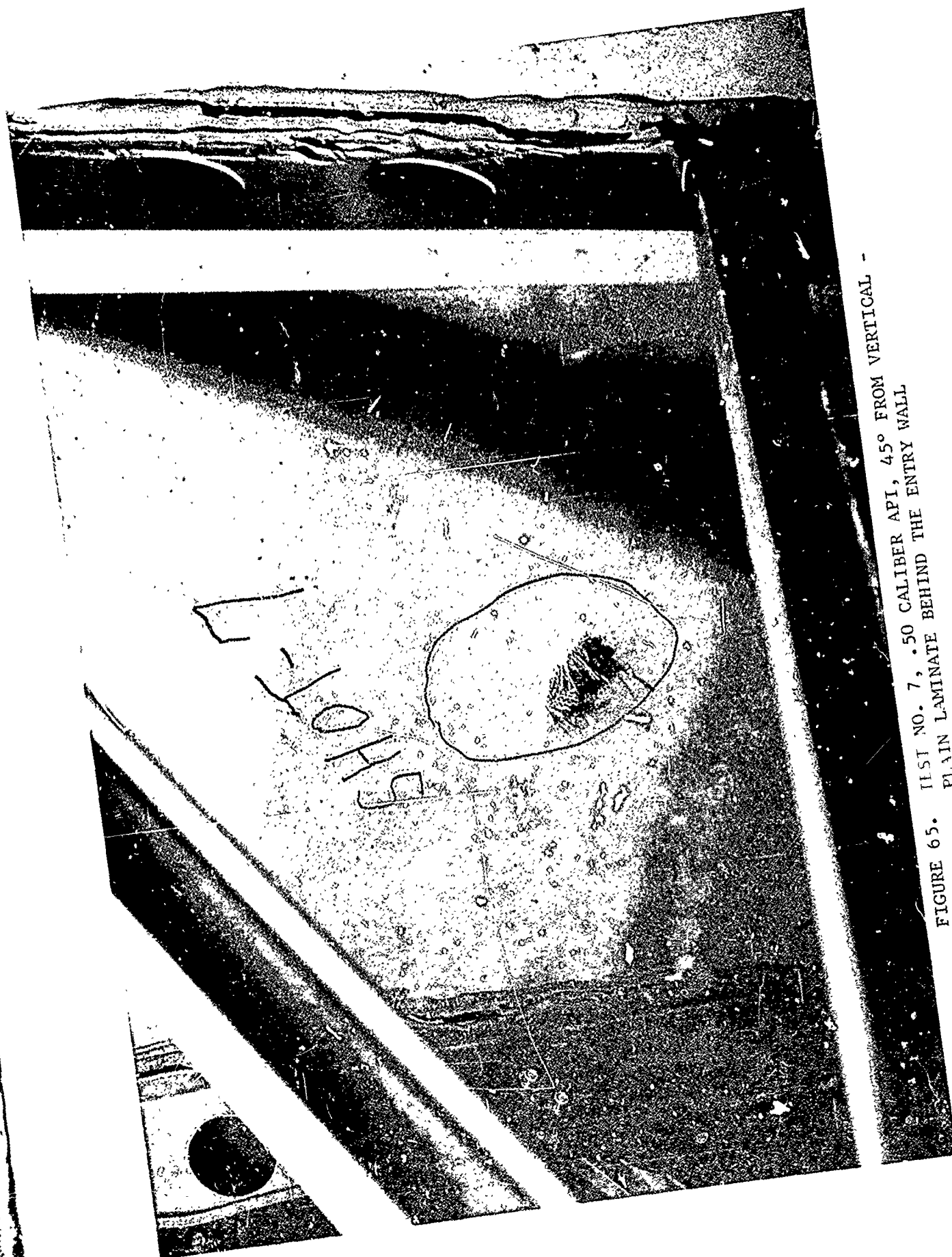


FIGURE 65. TEST NO. 7, .50 CALIBER API, 45° FROM VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL

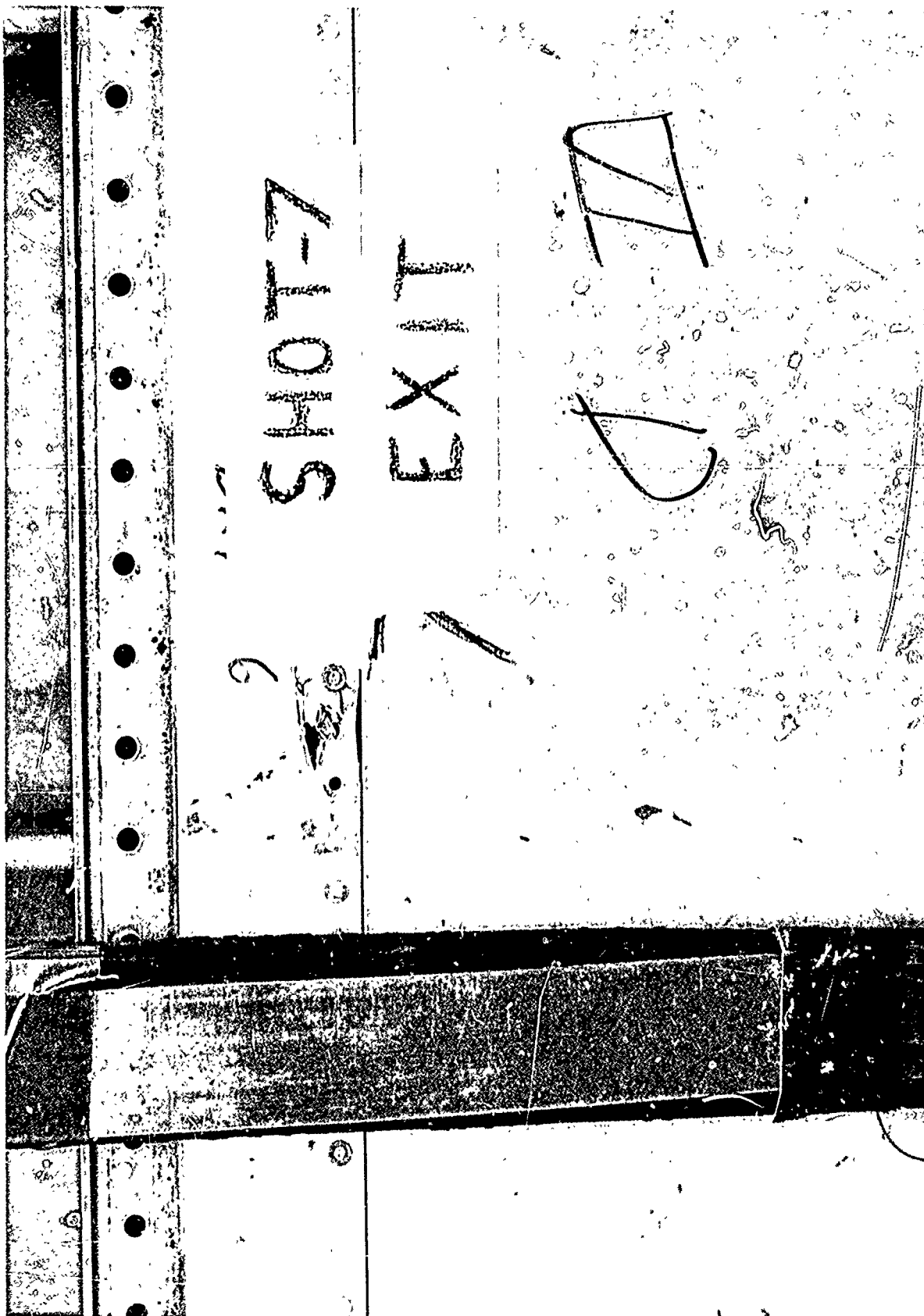


FIGURE 66. TEST NO. 7, .50 CALIBER API, 45° FROM VERTICAL -
EXIT FACE OF THE TANK

over several bays surrounding the impact area. This occurred immediately after impact and was witnessed in the high-speed films. This pressure phenomenon was responsible for the cracking of the tank entry skin as shown in Figure 67. Four major radial cracks occurred. The largest measured approximately 40-inches. The rib, which was hit by the projectile at the entry, was ruptured.

The corrugated laminate behind the cracked skin showed only a 1 3/4-inch rip, and the precompressed foam had reduced the projectile entry hole to approximately 1/4 inch. The plain laminate behind the entry metal skin showed minor damage (a 1 1/2-inch X 3/4-inch rip) in the area where the 20mm. projectile penetrated (see Figure 68). However, the adjacent vertical trusses, as shown in Figures 68, 50 and 53, were separated from the skin structure. This uncovered an area of the skin structure which did not have any protection. When the installation of the self-sealing system was performed, this area of the tank structure was inaccessible and no self-sealing protection could be installed. The major leakage was thus due to this separation of the trusses from the skin. The fuel infiltrated through this unprotected area and leaked out of the skin cracks. The leakage measured was approximately 7 liters/min.

After penetrating the entry wall of the tank, the tumbling projectile hit a piece of the vertical truss in OWS 351 prior to penetrating the tank exit wall. At the exit wall, the projectile impacted between two ribs in a fully tumbled condition. The corrugated laminate (seven-ply) suffered only a 3 1/2-inch long slit and a 4 1/2-inch X 1 3/4-inch metal piece was removed from the exit skin wall (Figure 69).

<u>Test No.</u>	<u>Ammunition</u>	<u>Direction</u>	<u>Area of Tank Hit</u>
9	.50 caliber AP	45° from Vertical (Forward to Aft)	Bay 8, X E

Results

For comparison purposes, a .50 caliber AP projectile was fired into Bay 8 (area X E) which did not contain any protection. That is, no damage control or self-sealing systems had been installed in this part of the tank. The projectile impacted the tank in a 45° angle of incidence. Figure 70 shows the fuel leakage immediately after impact. The leakage was too heavy to be measured. The damage at the tank entry metal skin is shown in Figure 71. A hole 2 1/4-inch X 3/4-inch and two cracks (6 inches and 16 inches long) were provoked as shown in the figure. Upon penetration of the tank entry wall, a rib was hit. At the exit side of the tank, the tumbling projectile hit two ribs including one with rivets. A 5-inch x 2 1/2-inch piece of metal was removed and there were cracks in the skin around the hole (See Figure 72).

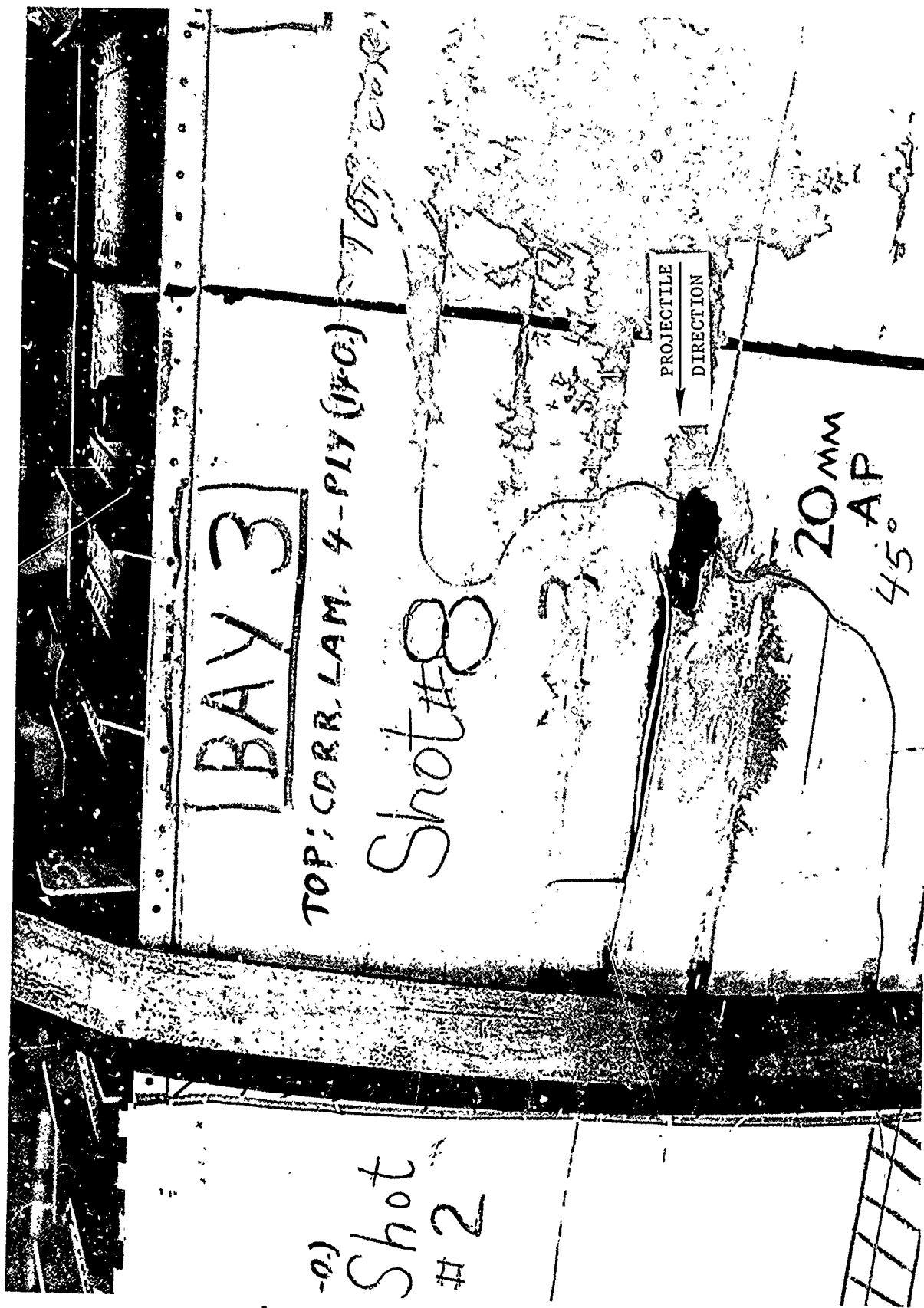


FIGURE 67. TEST NO. 8, 20MM AP, 45° FROM VERTICAL -
ENTRY FACE OF THE TANK

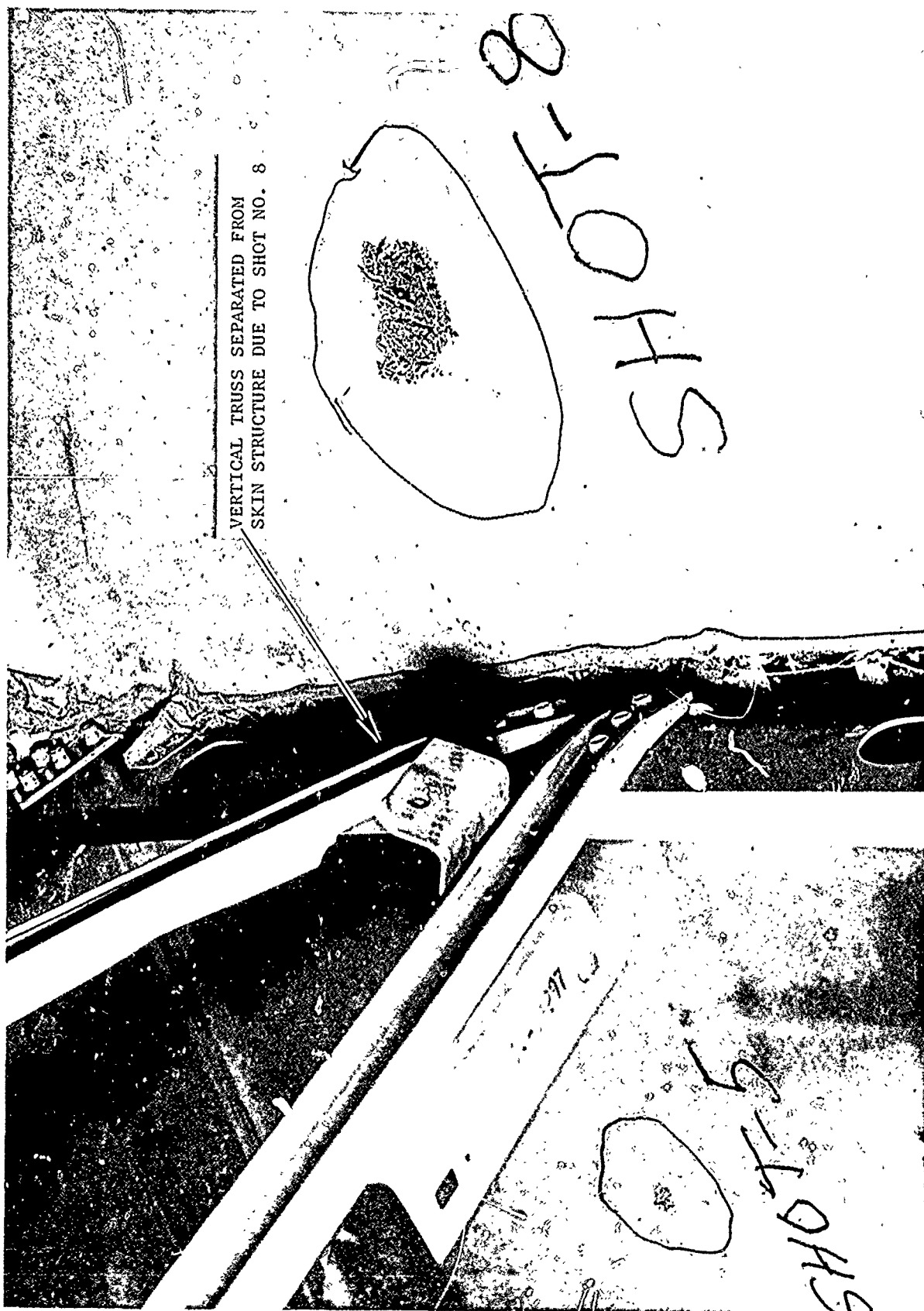


FIGURE 68. TEST NO. 8, 20MM AP, 45° FROM VERTICAL -
PLAIN LAMINATE BEHIND THE ENTRY WALL

EXIT

SHOT-8

X

SHOT-4

EXIT

ply top
(90°)

FIGURE 69. TEST NO. 8, 20MM AP, 45° FROM VERTICAL -
EXIT FACE OF THE TANK

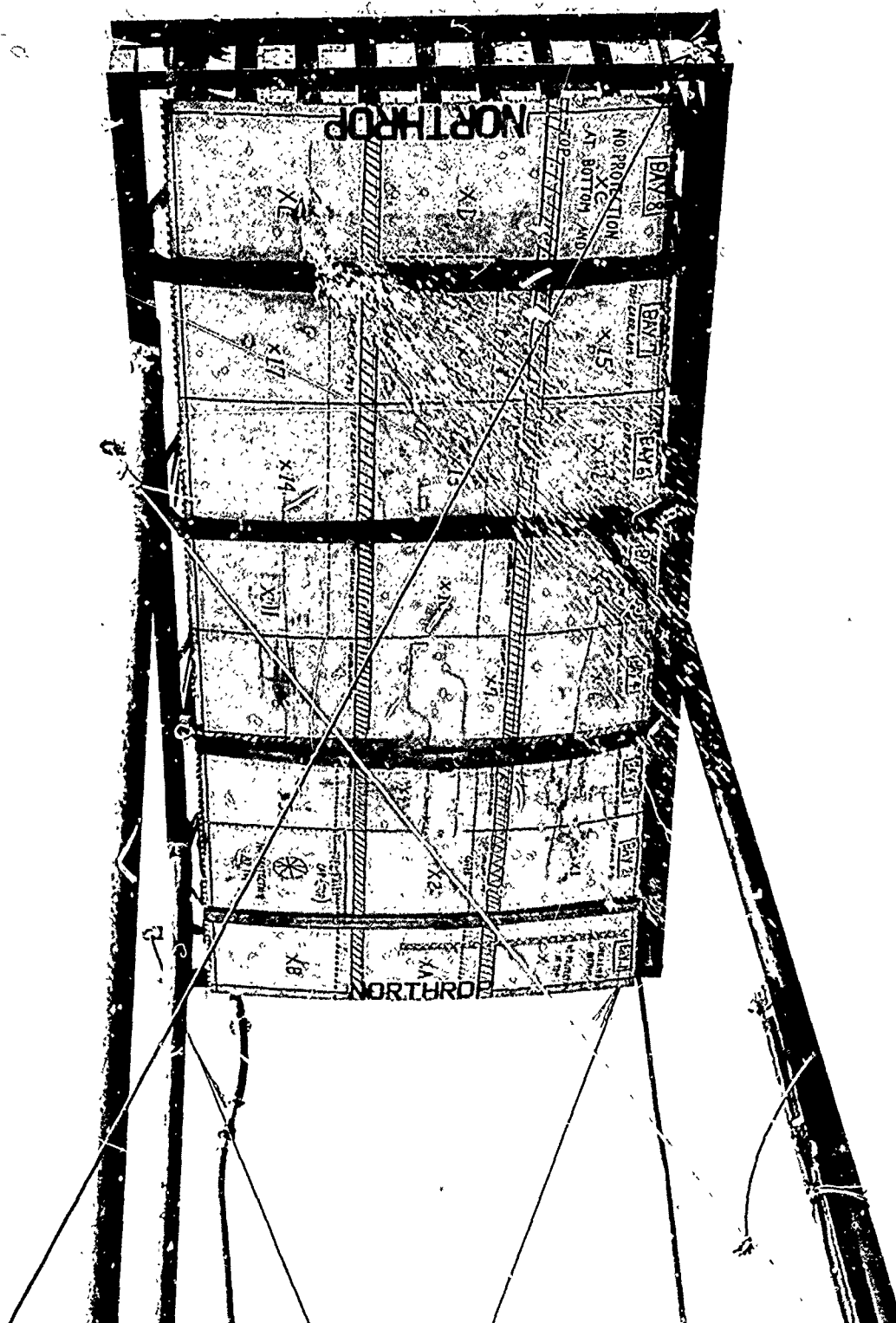


FIGURE 70. TEST NO. 9, .50 CALIBER AP, 45° FROM VERTICAL -
LEAKAGE OF FUEL AFTER IMPACT

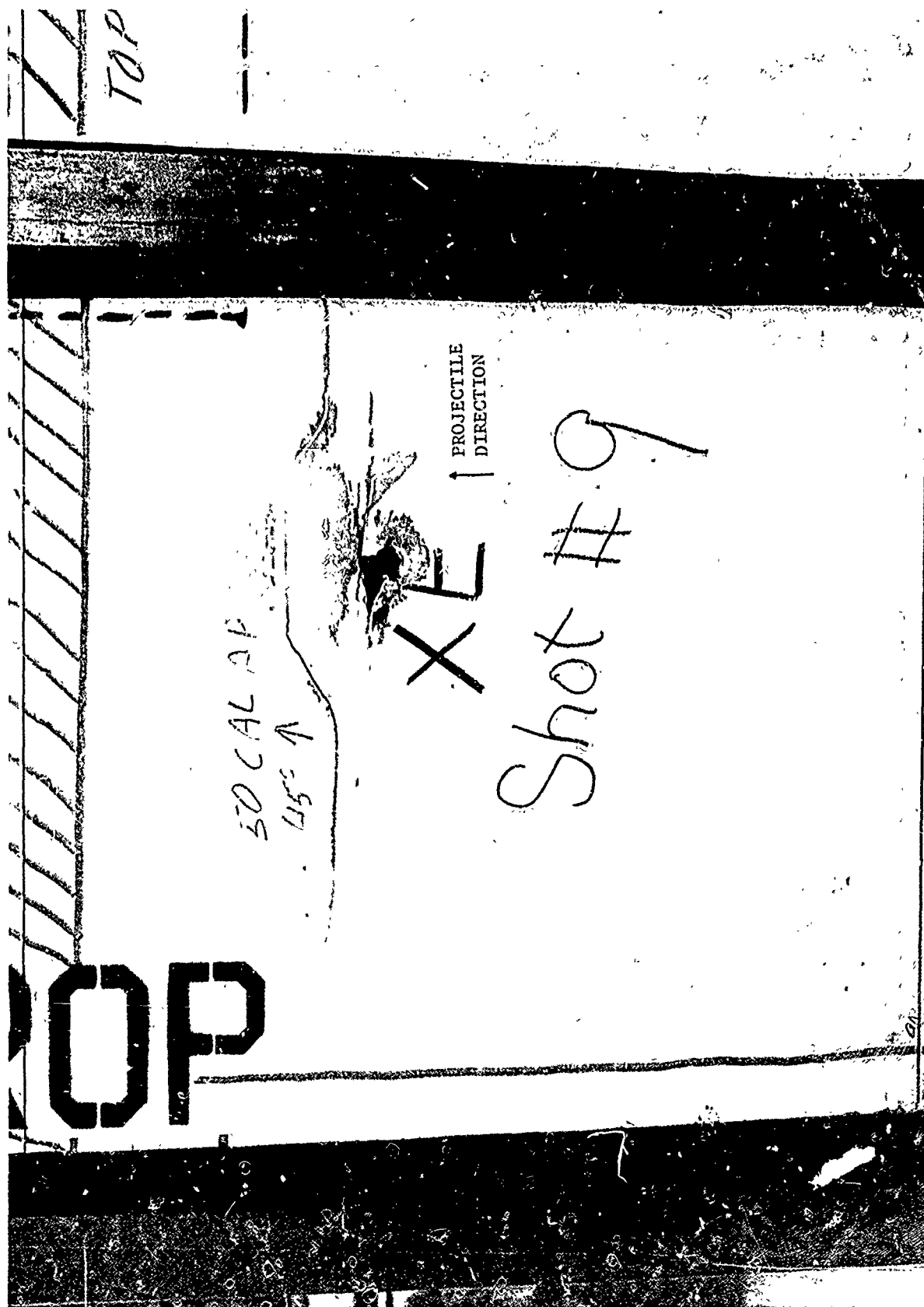


FIGURE 71. TEST NO. 9, .50 CALIBER AP 45° FROM VERTICAL -
ENTRY FACE OF THE TANK

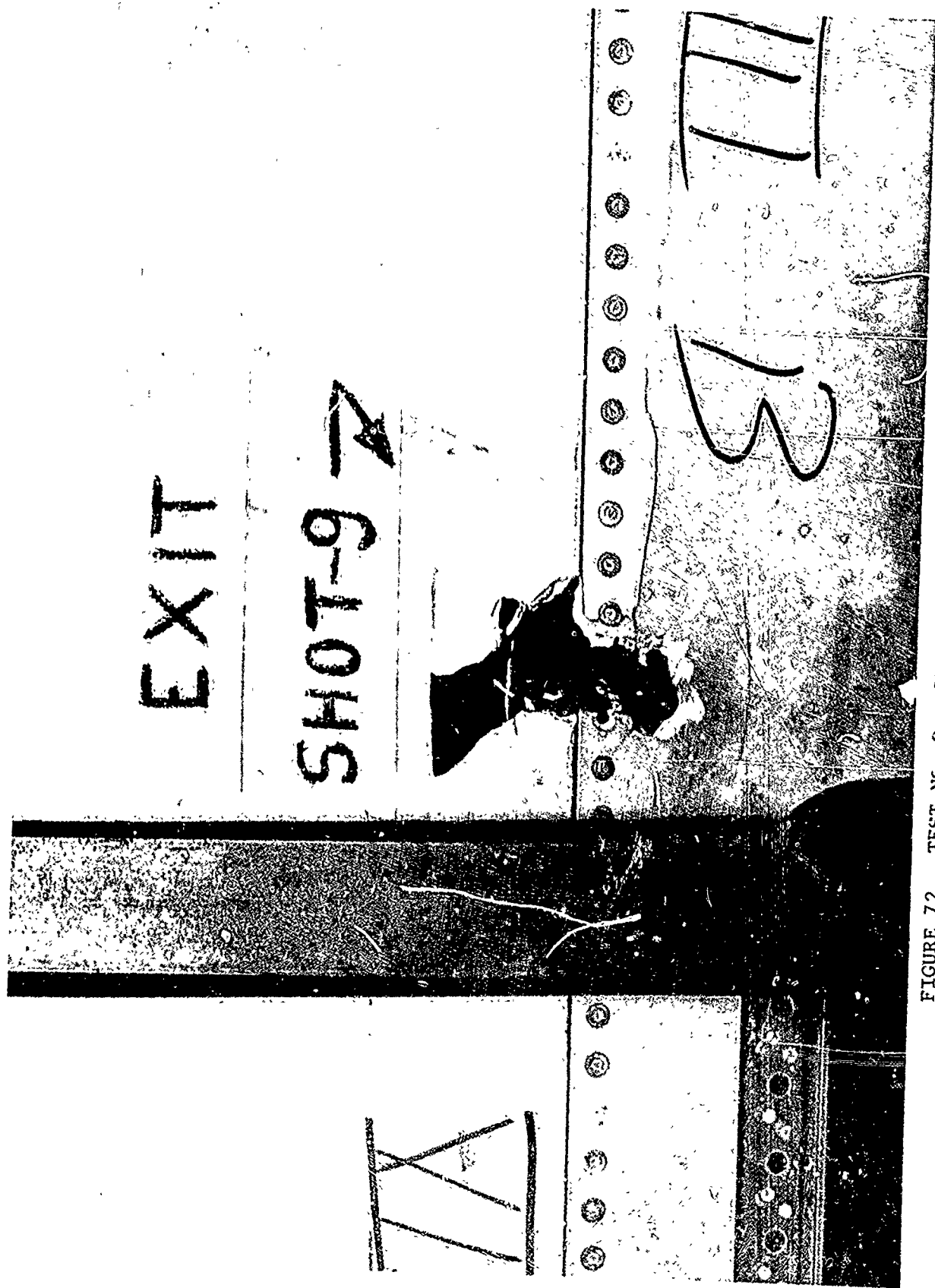


FIGURE 72. TEST NO. 9, .50 CALIBER AP, 45° FROM VERTICAL
EXIT FACE OF THE TANK

Although the damage caused by this projectile impact was extensive, it would have been greater had the tank been $2/3$ full of fuel. It is not known how much fuel remained in the tank when this shot was fired, but a substantial amount of fuel was noted to have escaped through the wounds of previous shots; consequently, destructive hydraulic ram pressure waves as intense as those created by previous projectile impacts could not have been produced in this instance.

A general view of the tank exit wall is given in Figure 73. This shows the damage provoked by all nine firing tests described above.



FIGURE 7. GENERAL VIEW OF TANK EXIT SIDE AFTER COMPLETION OF TESTS

SECTION III

SUMMARY AND CONCLUSIONS

A modification of a self-sealing system, developed under Contract F33615-70-C-1426, was used for the installation in the C-130 integral fuel tank. A sketch of this special system is given previously (Section II, Figure 1). It consists of a combination of flexible ballistic nylon laminates (corrugated and flat) and precompressed Buna-N closed-cell foam. This system was installed in two different C-130 tank sections, one for the slosh and vibration tests and one for the firing tests. In both tanks, all internal plumbing, fuel system components, and trailing edge fairings were removed. Closeout bulkheads, plates, clips, and stiffeners were fabricated and assembled into the two tanks. Prior to installation of the self-sealing system components, cracks, loose rivets, and loose vertical trusses in the tanks' skin structure were noted. This damage resulted from high static loads to which the tanks had been subjected in prior Lockheed tests.

The most promising and practical method used for fabrication of the corrugated laminates to be installed in the symmetrical sections of the tanks was the use of a C-130 wing skin section as a mold. For the asymmetrical sections, special molds were fabricated. The installation of the laminates (corrugated and flat) at the bottom part of the slosh and vibration test tank and at the bottom and top parts of the firing test tank, were performed by using 898 polysulfide sealant as the bonding agent and turn barrels for applying pressure during cure of the sealant. The precompressed foam, which is located between the ribs of the C-130 skin structure, is the self-sealing component of the self-sealing system. To put the foam in the precompressed state between the ribs, the foam strips were cut oversize. The foam also played the role of an absorber of the hydraulic ram pressure. The weight of the self-sealing system installed in the slosh and vibration tests tank was 1.70 pounds/foot². The thickness of the system exceeded the height of the structural ribs (5/8-inch) by 3/16 of an inch. The weight of the system installed in the firing tests tank was 1.85 pounds/foot², and its thickness exceeded the height of the structural ribs (7/8-inch) by 3/16 of an inch.

The C-130 fuel tank containing protection on the bottom part only was used for the slosh and vibration tests. The fuel used in these tests was JP-4. Inspection of the tank after tests revealed the following:

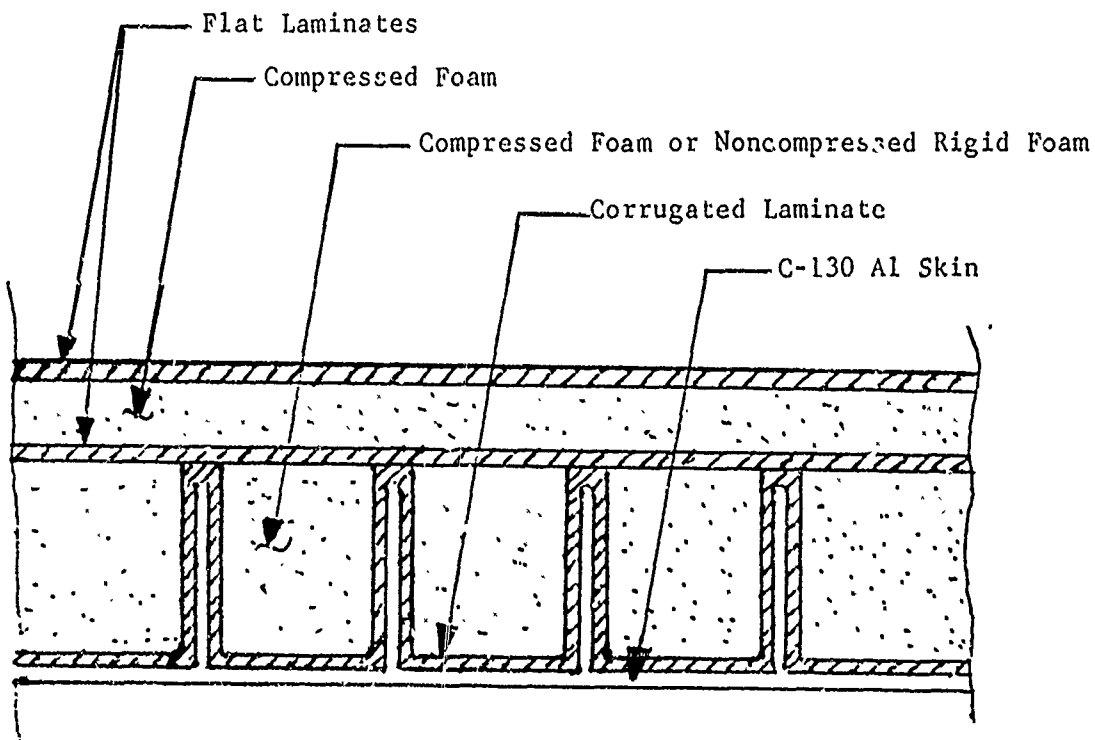
1. Excellent resistance of the protective system towards fuel and slosh and vibration.
2. No evidence of delamination or tearing of bonding of the damage control and self-sealing systems.
3. Two failed vertical trusses in the rib structure.

The C-130 fuel tank containing protection on the bottom and top parts of the tank was used for the firing tests. The type and caliber projectiles used in these tests were: .50 AP, .50 API and 20mm AP. All shots but one hit a rib. It is well known from preliminary tests that when a projectile hits an unprotected C-130 skin structure at a rib, either laterally or longitudinally, catastrophic rupturing of the skin structure occurs. By comparison, a hit between two ribs results in a clean hole in the skin and no rupturing. The results of these impact tests are summarized in the table following:

SHOT NUMBER	SIZE AND TYPE PROJECTILE	ANGLE OF ENTRY	INITIAL LEAKAGE RATE FUEL/MIN	REMARKS
1	.50 Cal. AP	Vertical	60 cc.	Projectile hit a rib on entry. Skin did not rupture. The rate of flow dropped to practically 0 after two hours.
2	.50 Cal. AP	45° from vertical (aft to forward)	30 cc.	Projectile hit a rib laterally on entry. The rate of flow dropped to almost 0 after two hours. Skin did not rupture.
3	.50 Cal. AP	45° from vertical (outboard to inboard)	3.2 liters	Projectile hit a rib longitudinally on entry. Projectile tumbled immediately behind entry skin. The skin and rib ruptured. The projectile did not exit the tank.
4	.50 Cal. AP	45° from vertical (forward to aft)	130 cc.	Projectile hit a rib on entry. Skin did not rupture. The leakage rate was reduced to 70 cc. about 45 minutes after the shot.
5	.50 Cal. AP	45° from vertical (inboard to outboard)	25 cc.	Projectile hit a rib on entry. Skin did not rupture. The leakage rate was reduced to 0 after one hour.
6	.50 Cal. API	Vertical	20 drops	Projectile did not hit a rib on entry. Skin did not rupture. The leakage rate dropped to 0 after one hour. Functioning of projectile took place after exit of tank.
7	.50 Cal. API	45° from vertical (inboard to outboard)	3 liters	Projectile hit a rib longitudinally, tumbled and functioned immediately behind the entry metal skin. Skin and rib were ruptured.
8	20mm	45° from vertical (inboard to outboard)	7 liters	Projectile hit a rib longitudinally. Projectile tumbled immediately behind the entry skin. Several cracks in entry skin occurred. The major leakage was due to separation of vertical trusses from the skin, which did not have any protective system.

SHOT NUMBER	SIZE AND TYPE PROJECTILE	ANGLE OF ENTRY	INITIAL LEAKAGE RATE FUEL/MIN	REMARKS
9	.50 Cal. AP	45° from vertical (forward to aft)	too heavy to be measured	In this shot, an unprotected section of the tank was impacted to compare with impacts in protected sections. This test was unrealistic because at the time of impact, the fuel level in the tank was very low and the hydraulic ram did not have its full effects as it would have in the case where fuel level is at the 2/3 full mark. The projectile hit a rib laterally on entry. Several cracks occurred around the impact hole and away from the impact hole. Heavy fuel leakage was obtained.

As indicated in the table above, four shots (1, 2, 5, and 6) out of eight shots (in protected sections) sealed. However, these seals were not obtained immediately. In these particular shots, an immediate seal could have been obtained if the degree of foam precompression would have been at a higher level, as for instance, 20%. Also, the use of a fast swelling foam material would have helped in accomplishing a fast seal. In the cases where a rib was squarely struck and badly distorted (shots 3, 4, 7, and 8), a modified materials construction, such as that shown below, where the compressed foam sealant component is placed over as well as between the ribs, would have been required to obtain seals.



An overall assessment of the damage sustained indicates that minor modifications of the compressed foam self-sealing concept could overcome the causes that prevented instantaneous seals. It is planned to investigate the self-sealing concept modifications suggested above and in Section IV of this report under the current integral fuel tank self-sealing materials research program.

SECTION IV

RECOMMENDATIONS FOR FUTURE WORK

1. The methods used for fabricating the corrugated laminates could be modified to save time and reduce the complexity of the process. For example, the wet laminate could be directly installed in the C-130 tank to conform to the tank skin structure, thus avoiding prefabrication of the corrugated laminate. Also, the 898 polysulfide sealant could be sprayed rather than troweled on the ballistic nylon cloth inside the tank.
2. The self-sealing efficiency could be improved by (a) increasing the degree of foam precompression between the ribs, (b) using a different class of foam materials which would not only seal mechanically but would also seal by swelling when in contact with the fuel; the degree and rate of swelling of the foam could be varied, and (c) the precompressed foam could be left unbonded or only partially bonded in place.
3. Instead of using a non-self-sealing flat laminate bonded on top of the foam and tank ribs, self-sealing bladder material could be used to enhance the sealing capability of the system.
4. To simplify the installation of the self-sealing system in the C-130 wing integral fuel tank, the complete system including the precompressed foam and top flat laminate could be prefabricated and then installed in the C-130 tank by sections.
5. Another approach would be to fill the space between the tank ribs with rigid foam. This would produce a flat inside surface. A self-sealing compressed foam sandwich construction could be bonded on top of the rigid foam and ribs. This system would only take up a little more fuel space than the construction used in this program.

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13. ABSTRACT <p>The objective of this program was to adapt a newly developed self-sealing integral fuel tank materials system to a C-130 integral wing tank and evaluate its resistance to slosh and vibration damage as well as its protective capabilities against small arms ground gunfire. The selected system consists of a combination of flexible ballistic nylon laminates (corrugated and flat) and precompressed Buna-N closed-cell foam.</p> <p>This system, when installed in a C-130 wing integral fuel tank section, was found to withstand slosh and vibration tests.</p> <p>In firing tests of this system installed in a C-130 wing integral fuel tank section, promising results were obtained. The damage control system proved successful in limiting the damage to the C-130 skin structure. The self-sealing system was successful for many .50 caliber AP and API impacts. When the projectiles hit a rib longitudinally and tumbled immediately behind the tank entry skin structure, large areas of the tank were damaged and sealing was only partially effective. When installed in the slosh and vibration tests tank, the weight of the system was 1.70 pounds/foot², and its thickness exceeded the height of the structural ribs (5/8-inch) by 3/16 of an inch. By comparison, when installed in the firing tests tank, the weight of the system was 1.85 pounds/foot², and its thickness exceeded the height of the structural ribs (7/8-inch) by 3/16 of an inch.</p>		

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